SUSY Studies for ATLAS at LHC

Frank E. Paige, Brookhaven National Laboratory

TeV-scale SUSY is attractive extension of Standard Model (SM). Gives:

- Natural explanation for $M_h \sim 100\,\mathrm{GeV}$ (but *not* for $\Lambda \sim 10^{-3}\,\mathrm{eV}$);
- Consistency of EW data from LEP, SLC, Tevatron with GUTs;
- Natural candidate ($\tilde{\chi}_1^0$) for cold dark matter.

SUSY gives complex signatures $\Rightarrow$ good test for ATLAS detector.

Outline of talk:

- Very brief review of SUSY models.
- Search for SUSY at LHC.
- Precise SUSY measurements: old examples plus new results.
- Full simulation of SUSY events for Athens.
- Outlook.

SUSY Models

Assume MSSM: minimal model, superpartner with $\Delta J = \pm 1/2$ for each SM particle, two Higgs doublets plus their partners [TDR, Intro].

General MSSM gives TeV-scale proton decay. Assume R-parity, with $R = (-1)^{3B-3L+2S}$. Then SUSY particles produced in pairs, and each decays to invisible LSP $\tilde{\chi}_1^0 \Rightarrow \not{E}_T$ and no mass peaks.

Higgs sector $\Rightarrow$ 5 physical states (h, H, A, $H^\pm$) with $M_h \lesssim 130\,\mathrm{GeV}$.

Gaugino superpartners of gauge and Higgs bosons mix to give

- Four neutralinos $\tilde{\chi}_i^0 \Leftrightarrow \tilde{\gamma}, \tilde{Z}, \tilde{H}_1^0, \tilde{H}_2^0$.
- Two charginos $\tilde{\chi}_i^\pm \Leftrightarrow \tilde{W}^\pm, \tilde{H}^\pm$.

MSSM has 105 new parameters. Often assume mSUGRA model: SUSY breaking through supergravity with just 4 parameters plus a sign:

$$m_0, \quad m_{1/2}, \quad A_0, \quad \tan\beta, \quad \mathrm{sgn}\,\mu = \pm 1\,.$$

Search for SUSY Particles at LHC

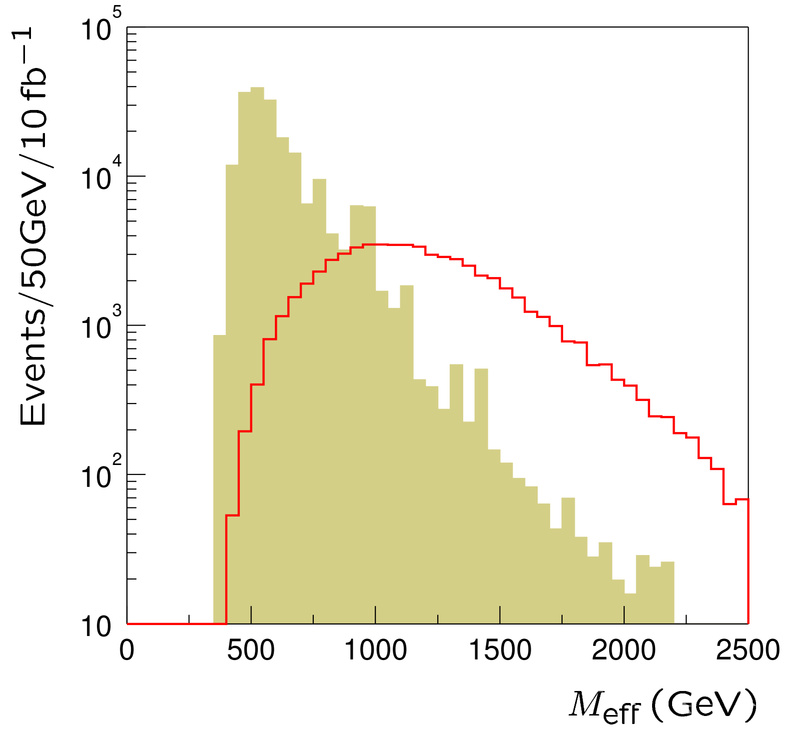
SUSY production at LHC dominated by $\tilde{g}$ and $\tilde{q}$.

Strongly produced, so cross sections comparable to jets at similar Q^2. Decays to $\tilde{\chi}_1^0$ give large $\not\!\!E_T$.

Example: mSUGRA with $m_0 = 100\,\mathrm{GeV}$, $m_{1/2} = 300\,\mathrm{GeV}$, $A_0 = 0$, $\tan\beta = 10$, $\mathrm{sgn}\,\mu = +$.

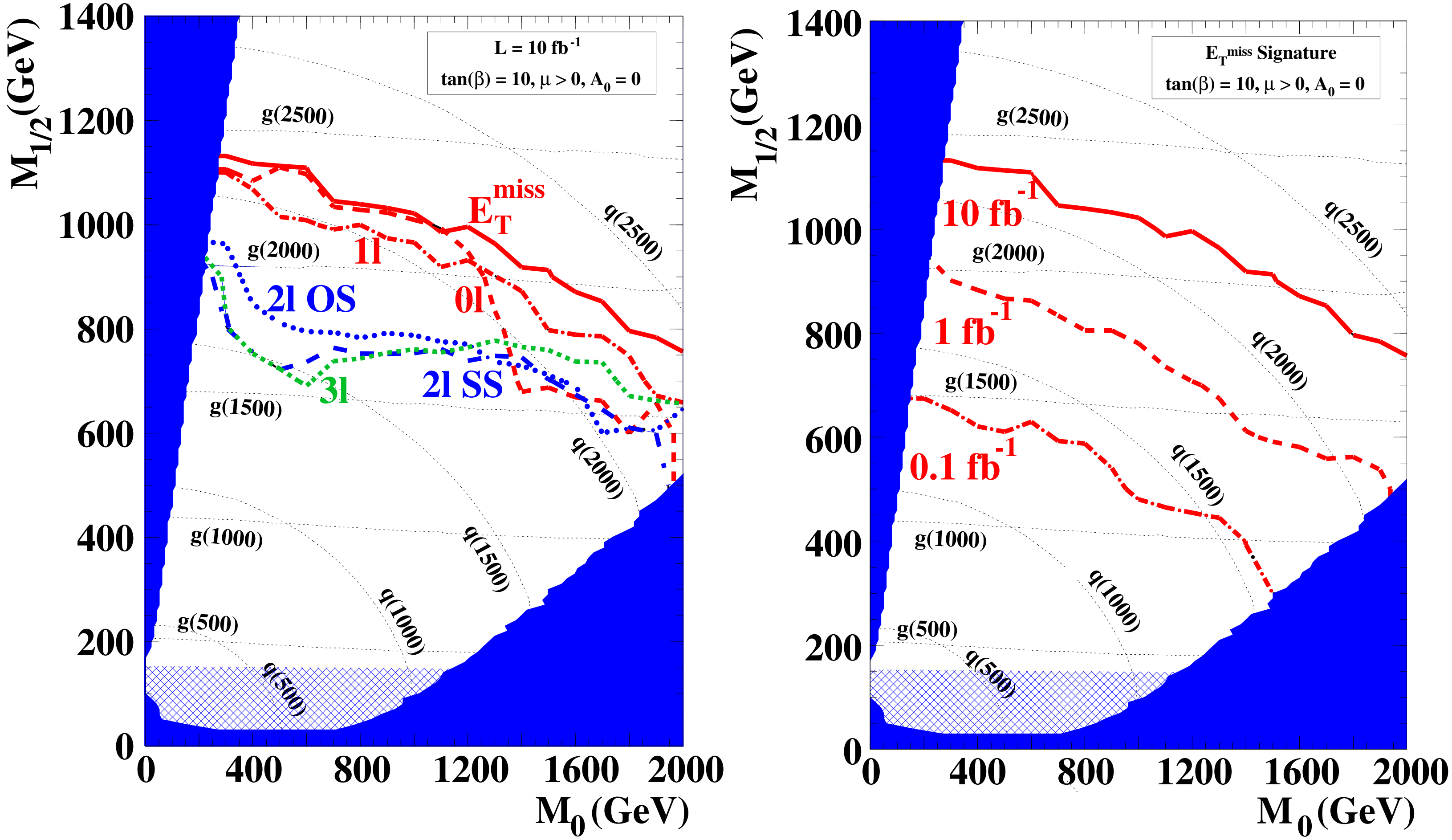
Require $\not\!\!E_T > 100\,\mathrm{GeV}$, ≥ 4 jets with $E_T > 100, 50, 50, 50\,\mathrm{GeV}$, and plot

$$M_{\mathrm{eff}} = \not\!\!E_T + \sum_j E_{T,j}$$



Clean SUSY signal for large M_{eff} with reasonable efficiency.

Requiring $S > 10$ and $S/\sqrt{B} > 5$ gives reach $M > 1\,\mathrm{TeV}$ with $0.1\,\mathrm{fb}^{-1}$ and $M > 2\,\mathrm{TeV}$ with $10\,\mathrm{fb}^{-1}$ for $\tilde{g}, \tilde{q}$ [Tovey]:



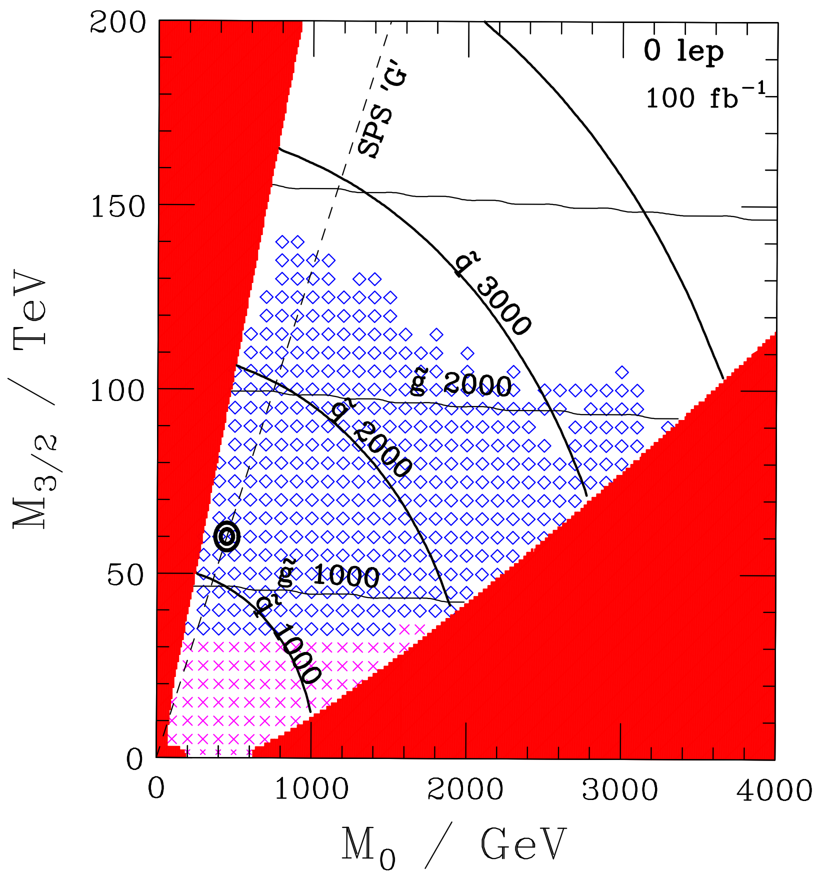
Should find TeV-scale SUSY quickly at LHC.

Similar $M_{\tilde{g}}, M_{\tilde{q}}$ reach in AMSB model, $M > 2\,\text{TeV}$ for $100\,\text{fb}^{-1}$ with lepton veto [Barr]:

MSSM particle masses in AMSB are produced from $\tilde{G}$ mass $m_{3/2}$ via anomalies. May dominate if other contributions vanish.

Pure AMSB model gives tachyons. Add scalar mass m_0 to fix problem.

Gaugino spectrum is quite different than mSUGRA.



Reach depends mainly on $\sigma(M_{\tilde{g}}, M_{\tilde{q}})$ and $M_{\tilde{\chi}_1^0} \ll M_{\tilde{g}}, M_{\tilde{q}}$. Expect similar result in most R-conserving models.

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SUSY Particle Measurements

After "Observation of anomalous multijet + $\not\!\!E_T$ events at LHC"....

R parity $\Rightarrow$ invisible LSP, so no mass peaks. But can measure kinematic endpoints $\Rightarrow$ mass combinations.

Simplest case: $\tilde\chi_2^0 \to \tilde\chi_1^0 \ell^+\ell^-$ gives dilepton endpoint at

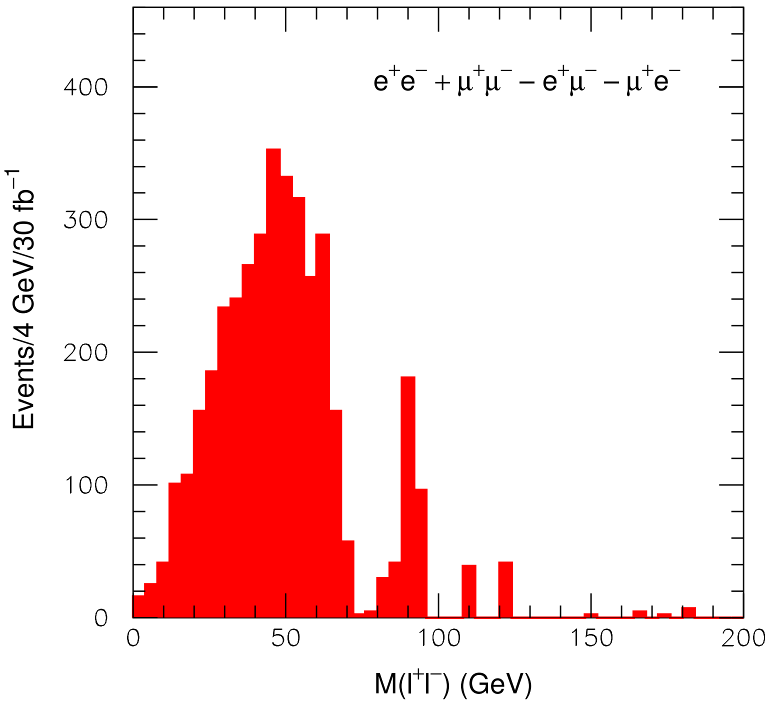
$$M_{\ell\ell}^{\max} = M_{\tilde\chi_2^0} - M_{\tilde\chi_1^0}$$

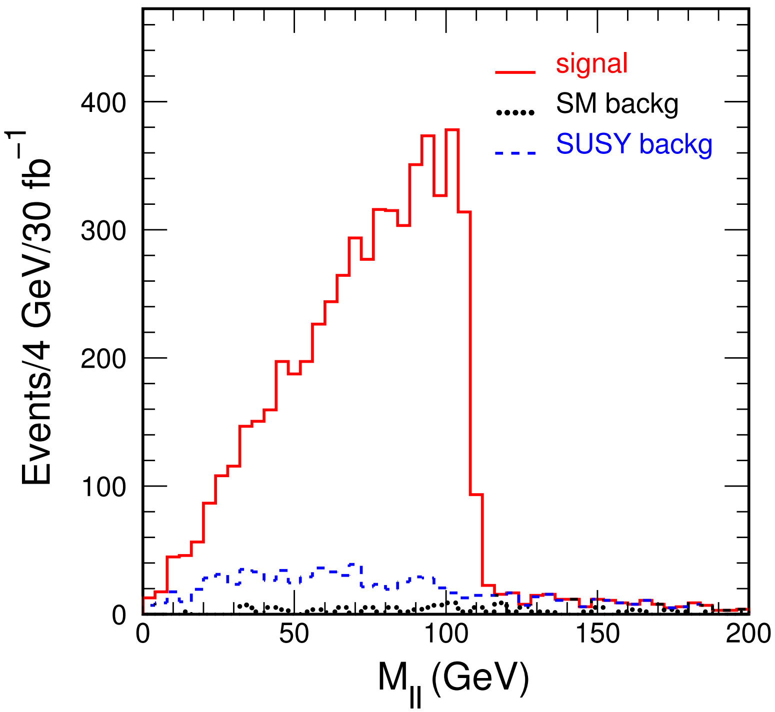
Cascade decay $\tilde\chi_2^0 \to \tilde\ell^\pm \ell^\mp \to \tilde\chi_1^0 \ell^+\ell^-$ gives endpoint at

$$M_{\ell\ell}^{\max} = \frac{1}{M_{\tilde\ell}} \sqrt{(M_{\tilde\chi_2^0}^2 - M_{\tilde\ell}^2)(M_{\tilde\ell}^2 - M_{\tilde\chi_1^0}^2)}$$

Require 2 isolated leptons, multiple jets, and large $\not\!\!E_T$ $\Rightarrow$ main SM background is $t\bar t$. Form combination $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ to cancel independent decays from SM or SUSY.

Examples of $M_{\ell\ell}$ for SUGRA points with $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-, \tilde{\chi}_1^0 Z$ (left) and for $\tilde{\chi}_2^0 \to \tilde{\ell}_R^\pm \ell^\mp$ (right) [TDR]:





Note $\tilde{\chi}_2^0 \to \tilde{\ell}_R^\pm \ell^\mp$ gives sharp $M_{\ell\ell}$ edge only smeared by resolution. Can distinguish from direct 3-body decay by shape.

Long decay chains allow more measurements. Dominant source of $\tilde{\chi}_2^0$ at SUGRA Point 5 (and similar points) is [TDR]

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\ell}_R^{\pm} \ell^{\mp} q \to \tilde{\chi}_1^0 \ell^+ \ell^- q$$

Assume 2 hardest jets are from squarks; combine each of these with leptons to form:

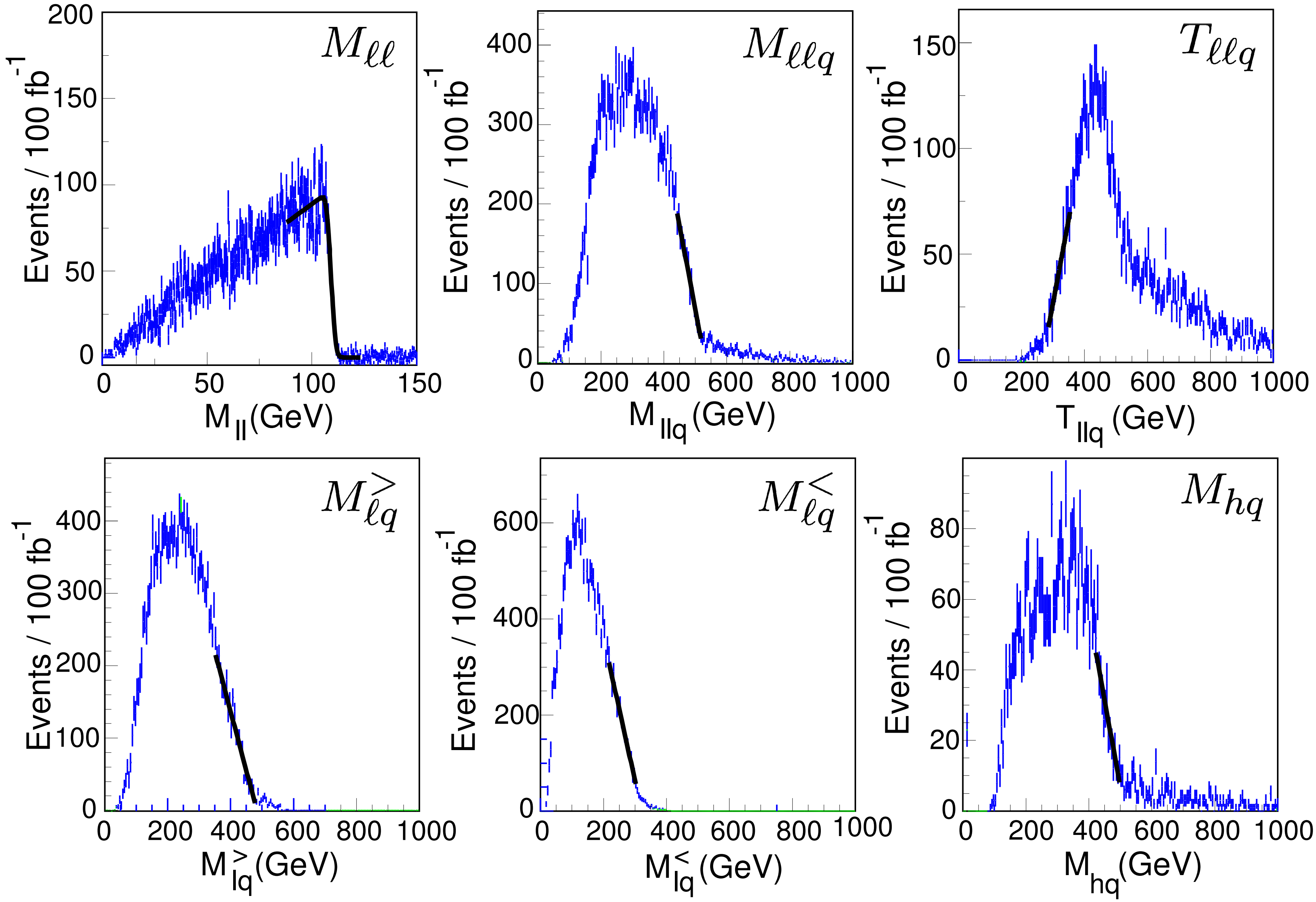
- Endpoints $M_{\ell\ell q}$, $M_{\ell q}^{(>)}$, $M_{\ell q}^{(<)}$;
- Threshold $T_{\ell\ell q}$ requiring $M_{\ell\ell} > cM_{\ell\ell}^{\max}$ ($c = 1/\sqrt{2}$).

Also have (see later):

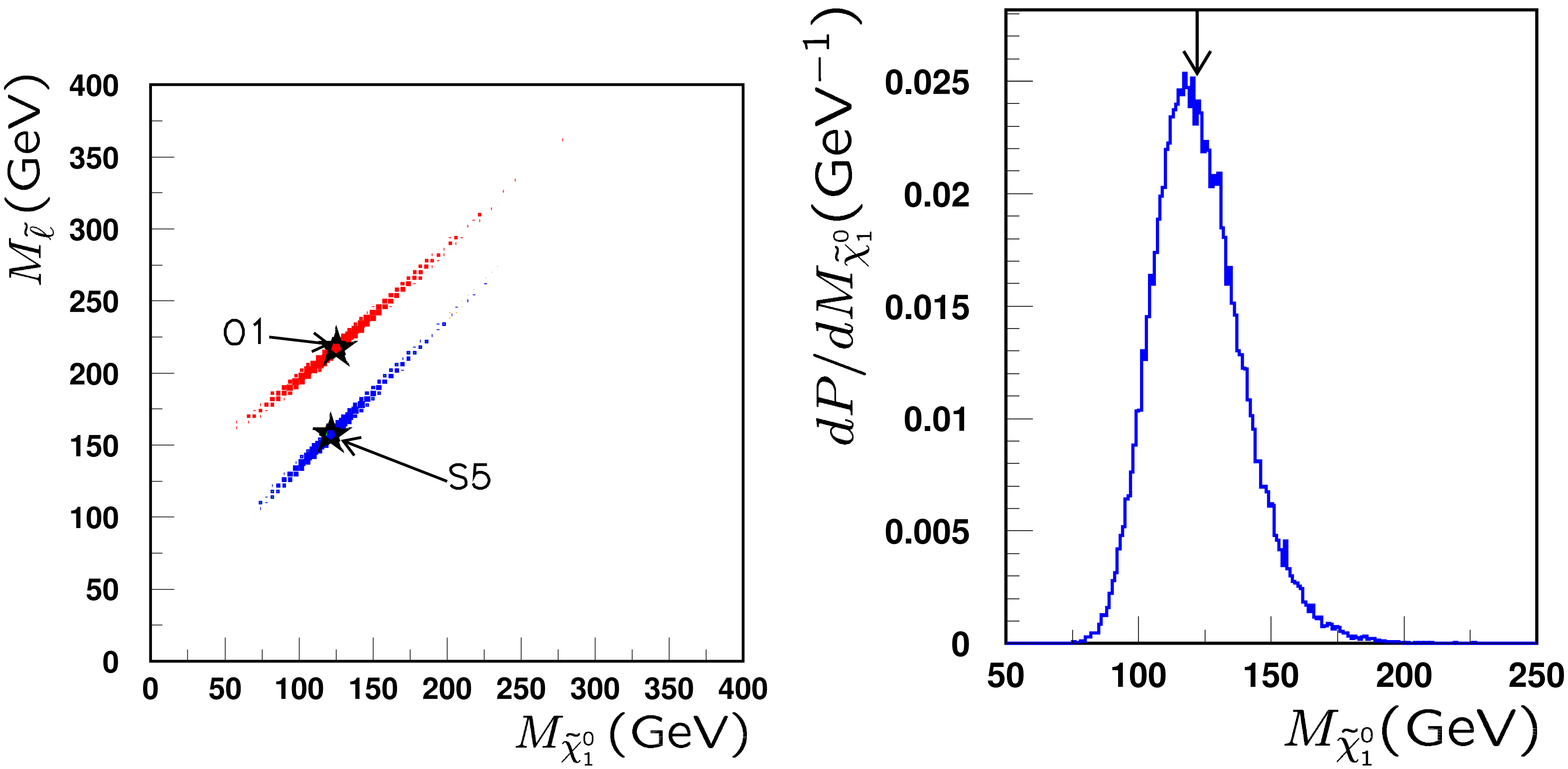
- Endpoint M_{hq} from $h \to b\bar{b}$.

Enough constraints to determine all masses involved(!). Can measure mass relations to $\sim 1\%$ as functions of LSP mass, determined to $\sim 10\%$.

Distributions for *TDR* mSUGRA Point 5 [Allanach]:


$M_{\ell\ell}$
Events / 100 fb^{-1}
M_{ll}(GeV)
$M_{\ell\ell q}$
M_{llq} (GeV)
$T_{\ell\ell q}$
T_{llq} (GeV)
$M^{>}_{\ell q}$
$M^{>}_{lq}$(GeV)
$M^{<}_{\ell q}$
$M^{<}_{lq}$ (GeV)
M_{hq}
M_{hq}(GeV)

Fits for masses from measurements for *TDR* mSUGRA Point 5 (S5) and "Optimized String Model" (O1) with similar masses:



Models clearly distinguished, but LSP mass only determined to $\sim 10\%$:

- LSP mass is small; effect on kinematics vanishes as $M_{\tilde{\chi}_1^0} \to 0$.
- QCD radiation smears $\ell\ell q$ threshold.

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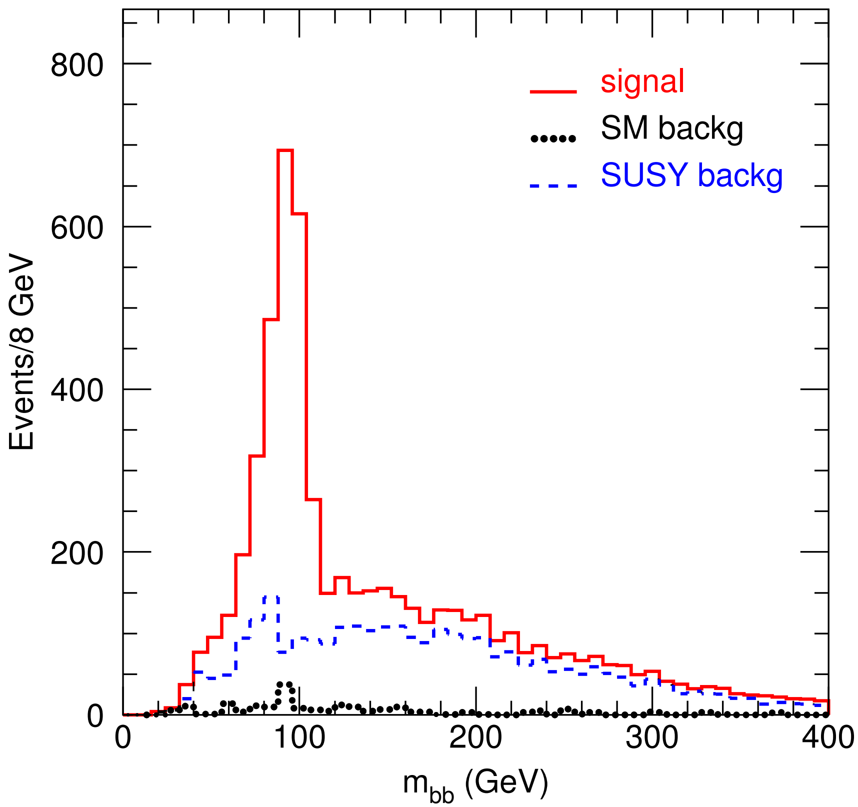
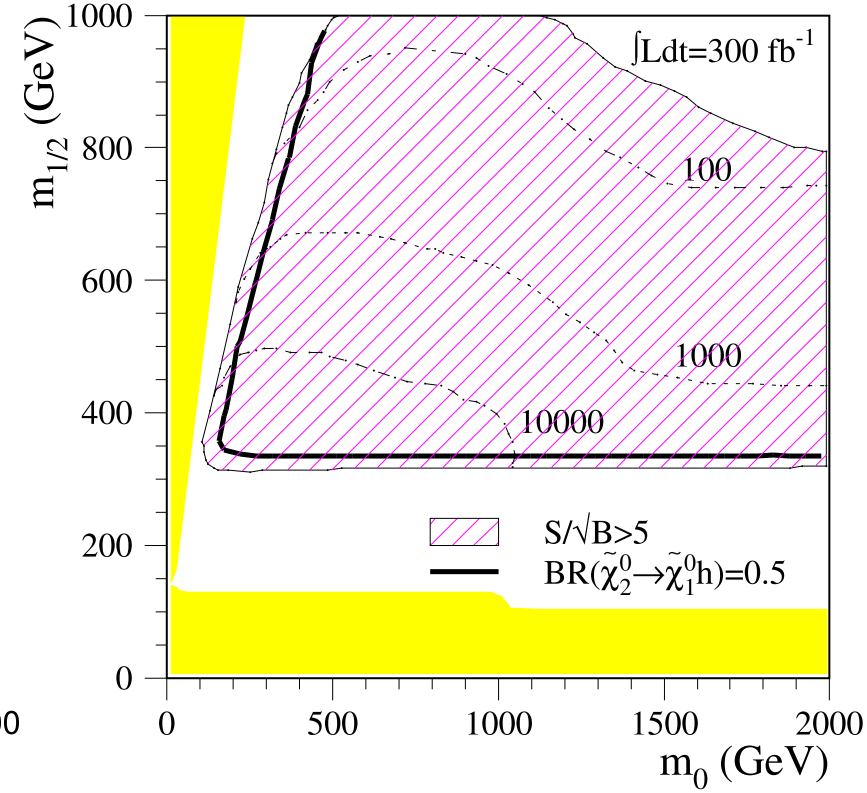
$h \to b\bar{b}$ Signatures

Rate for $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ may dominate $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell\ell$. Can reconstruct using two tagged b jets. Typical signal (Point 5) and 5σ reach for $300\,\mathrm{fb}^{-1}$ [TDR]:





Might be discovery mode for light Higgs.

Heavy Gaugino Signatures

Light gauginos typically dominate cascade decays:

$$B(\tilde{q}_L \to \tilde{\chi}_2^0 q) \sim 1/3, \quad B(\tilde{q}_L \to \tilde{\chi}_1^\pm q') \sim 2/3, \quad B(\tilde{q}_R \to \tilde{\chi}_1^0 q) \sim 1.$$

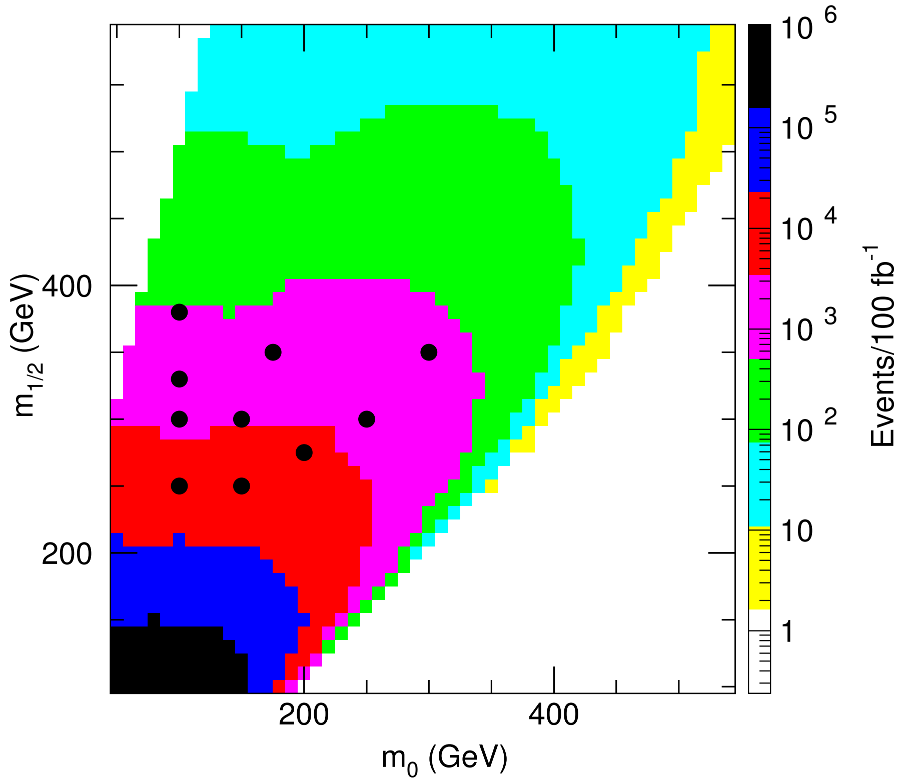
While heavy gauginos mainly Higgsino, mSUGRA gives some $\tilde{\chi}_4^0$ and $\tilde{\chi}_2^\pm$ decays. New analysis looks for dileptons beyond $\tilde{\chi}_2^0$ edge [Polesello]:

Four $\tilde{\chi}_4^0/\tilde{\chi}_2^\pm$ decay chains give OS, SF dileptons:

$$\begin{aligned}
&\tilde{q}_L \to \tilde{\chi}_4^0\, q \\
&\quad \hookrightarrow \tilde{\ell}_R^\pm \ell^\mp \\
&\qquad \hookrightarrow \tilde{\chi}_1^0 \ell^\pm \; [D1]
\end{aligned}
\qquad
\begin{aligned}
&\tilde{q}_L \to \tilde{\chi}_4^0\, q \\
&\quad \hookrightarrow \tilde{\ell}_L^\pm \ell^\mp \\
&\qquad \hookrightarrow \tilde{\chi}_1^0 \ell^\pm \; [D2] \\
&\qquad \hookrightarrow \tilde{\chi}_2^0 \ell^\pm \; [D3]
\end{aligned}
\qquad
\begin{aligned}
&\tilde{q}_L \to \tilde{\chi}_2^\pm\, q' \\
&\quad \hookrightarrow \tilde{\nu}_\ell \ell^\pm \\
&\qquad \hookrightarrow \tilde{\chi}_1^\pm \ell^\mp \; [D4]
\end{aligned}$$

Again can use $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ to cancel backgrounds.

Have $> 10^3$ $\ell^+\ell^-$ events from heavy gauginos over substantial range of mSUGRA parameters.



Analyze specific points: $\tilde{\chi}_4^0$ dominates for low m_0, while $\tilde{\chi}_2^\pm$ dominates for diagonal line.

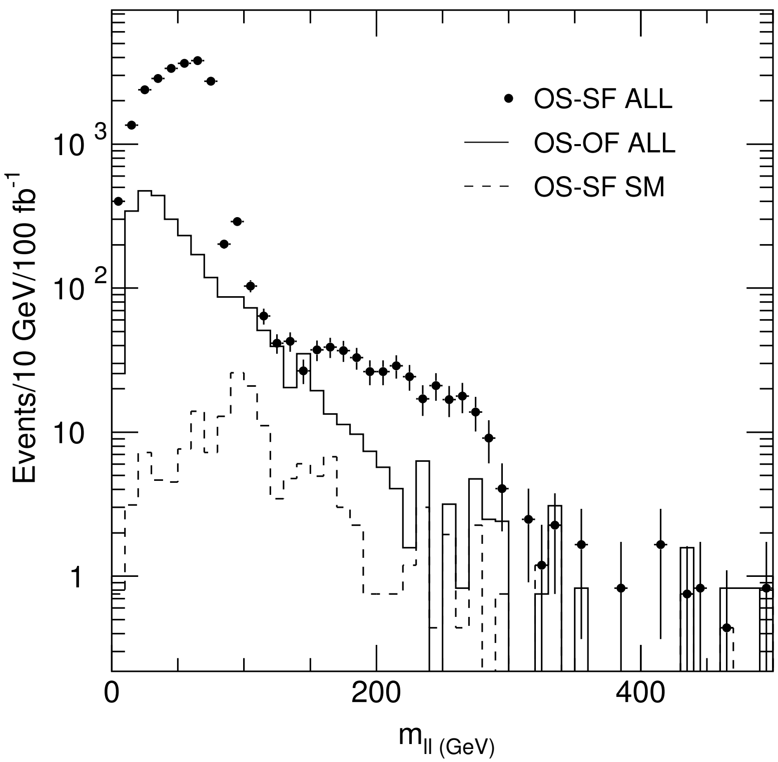
Require $\ell^+\ell^-$, $M_{\ell\ell} > 100\,\mathrm{GeV}$, $\not{E}_T > 100\,\mathrm{GeV}$, ≥ 4 jets, and $M_{\mathrm{eff}} > 600\,\mathrm{GeV}$.

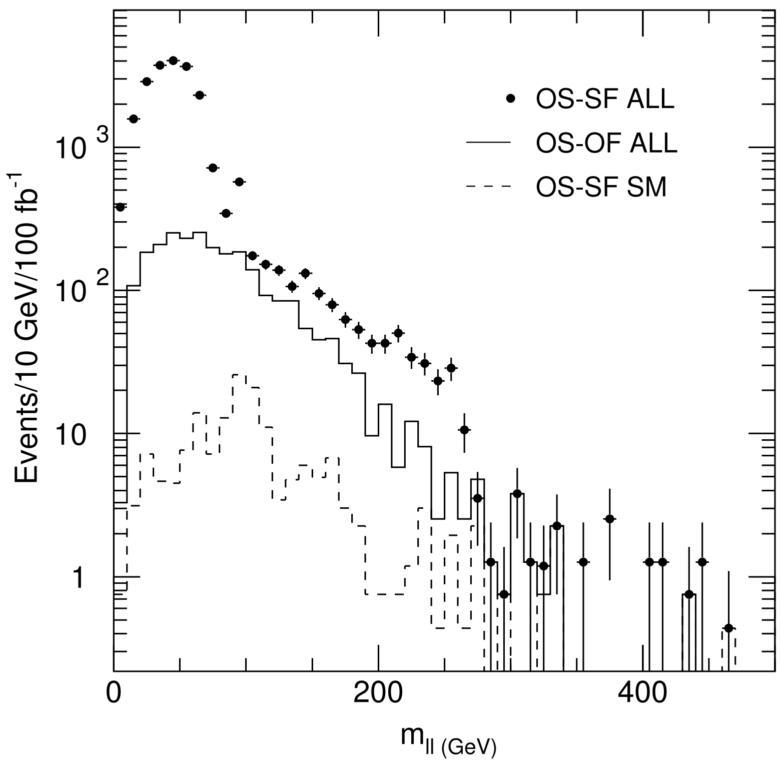
To suppress SM backgrounds, also require $M_{T2} > 80\,\mathrm{GeV}$ for minimum transverse mass for $\ell + \not{E}_T$, where

$$M_{T2}^2 \equiv \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left[\max\left\{m_T(p_{T\ell_1}, \not{p}_1), m_T(p_{T\ell_2}, \not{p}_2)\right\}\right]$$

Note $M_{T2} < M_W$ for t and W backgrounds.

Results for Point A (100,250) and Point E(150,250):





Observe small but clear excess over OS,OF SUSY and SM backgrounds.

Can measure endpoints to $\sim 4\,\mathrm{GeV}$ for Points A,E.

Heavy gaugino signals are hard but not impossible.

Third-Generation Squark Signatures

$\tilde{b}_{1,2}$ and $\tilde{t}_{1,2}$ are important for understanding SUSY model, but signatures are typically complex [Kawagoe].

Main source is $\tilde{g}$ decays. Consider for mSUGRA with $m_0 = 100\,\mathrm{GeV}$, $m_{1/2} = 300\,\mathrm{GeV}$, $A_0 = -300\,\mathrm{GeV}$, $\tan\beta = 10$, $\mathrm{sgn}\,\mu = +$:

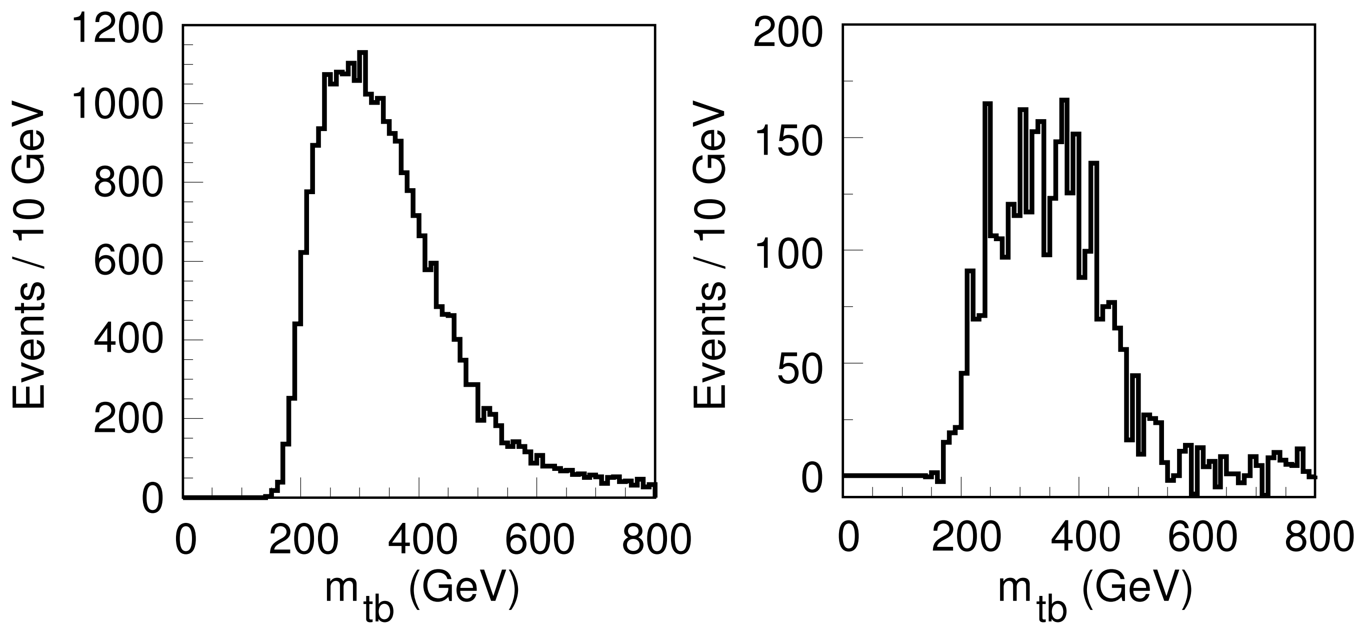
$$\tilde{g} \to t\tilde{t}_1^* \to t\bar{b}\tilde{\chi}_1^-, \qquad \tilde{g} \to \bar{b}\tilde{b}_1 \to \bar{b}t\tilde{\chi}_1^- .$$

Then $M(t\bar{b})$ endpoint measures combination $M_{\tilde{g}} - M_{\tilde{\chi}_1^-}$.

Analysis outline: Select SUSY events using cuts like those above. Require 2 b-tagged jets and two non-b jets j consistent with $t\bar{b} \to jjb\bar{b}$. Resulting $M_{jjb\bar{b}}$ distribution dominated by combinatorial background.

Select sidebands around $M_{jj} = M_W$, rescale their momenta to M_W, and subtract to determine $t\bar{b}$ signal.

$M(t\bar{b})$ mass distributions before and after subtraction:



Fitted endpoint is $443.2 \pm 7.4\,\mathrm{GeV}$ compared to expected $459\,\mathrm{GeV}$. Similar agreement between reconstructed and expected endpoints for 12 points studied.

Important to investigate similar sideband-subtraction methods for other multi-jet SUSY signatures.

τ Signatures

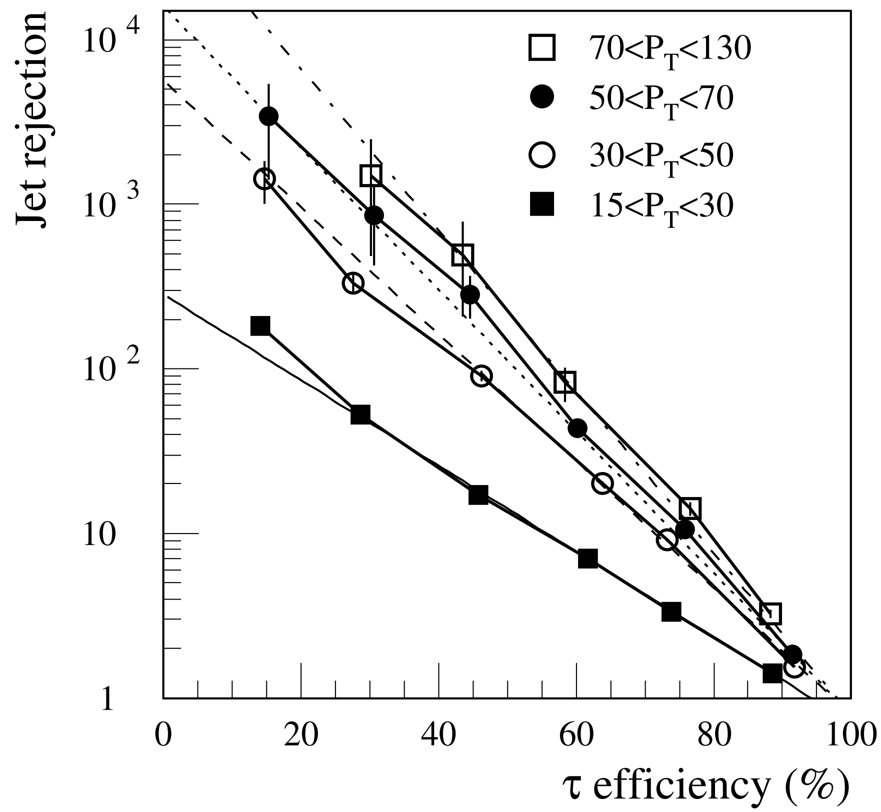
Expect $\tilde{e}$-$\tilde{\mu}$ universality since $\mu \not\to e\gamma$, but $\tilde{\tau}$ split by Yukawa contributions to RGE's, gaugino-Higgino mixing, and $\tilde{\tau}_L$-$\tilde{\tau}_R$ ($\propto m_\tau$).

τ's provide unique information, e.g., chirality, and might even be dominant, especially for $\tan\beta \gg 1$.

LHC vertex detectors cannot cleanly identify $\tau \to \ell\nu\bar{\nu}$.

Must rely on hadronic decays $\Rightarrow$ narrow, 1-prong jets. Large QCD background.

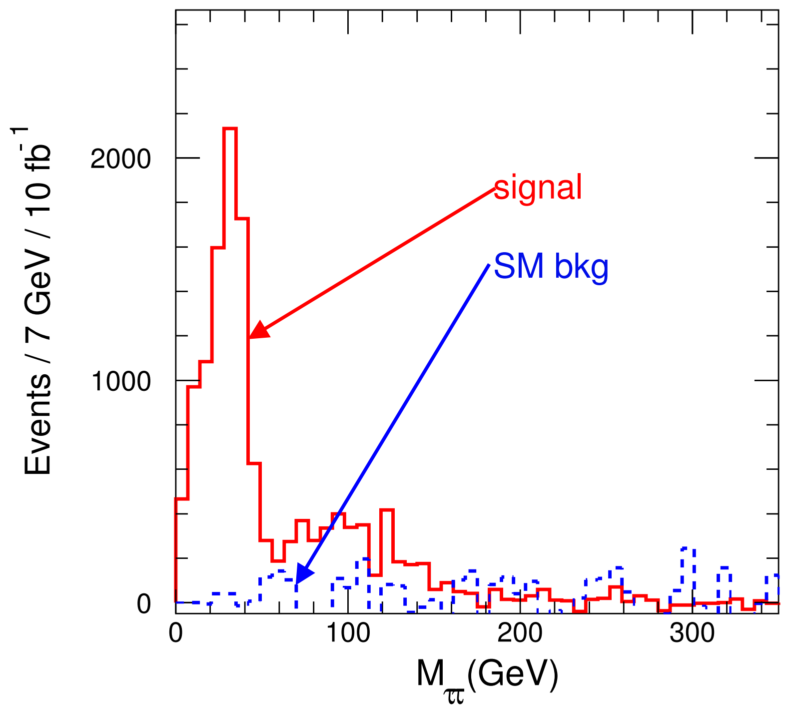
Can typically achieve $\tau/\mathrm{jet} \sim 100$ for $\varepsilon_\tau \sim 50\%$ [TDR]. Much worse than for e, μ.



For $H, A \to \tau\tau$ can use $\not{E}_T$ to reconstruct $\tau\tau$ mass. Not useful for SUSY because of $\tilde{\chi}_1^0$'s; must infer τ momentum from visible decay products.

Minimal SUGRA model with $m_0 = m_{1/2} = 200\,\mathrm{GeV}$, $A_0 = 0$, $\tan\beta = 45$ gives dominant $\tilde{\chi}_2^0 \to \tilde{\tau}_1\tau$ and $\tilde{\chi}_1^\pm \to \tilde{\tau}_1\nu_\tau$ decays.

Simple model for detector response turns sharp edge at $59.6\,\mathrm{GeV}$ into figure at right [TDR].



Visible τ momentum depends on both $\vec{p}_\tau$ and λ_τ; for $\tau \to \pi\nu$

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}(1 + \lambda_\tau \cos\theta^*)$$

while $\tau \to a_1\nu$ weakly dependent on λ_τ. Must separate decay modes.

SUSY Reconstruction with Athena 6.0.3

Have chosen mSUGRA point similar to *TDR* Point 5 but consistent with current bounds (e.g., $M_h = 114.8\,\mathrm{GeV}$):

$$m_0 = 100\,\mathrm{GeV},\ m_{1/2} = 300\,\mathrm{GeV},\ A_0 = -300\,\mathrm{GeV},\ \tan\beta = 6,\ \mathrm{sgn}\,\mu = +$$

Point chosen to have $\tilde{\chi}_2^0 \to \tilde{\ell}_R^{\pm}\ell^{\mp}$ (8.8%) signature like Point 5. Also gives $\tilde{\chi}_2^0 \to \tilde{\tau}_1^{\pm}\tau^{\mp}$ (75%) and $\tilde{\chi}_1^{\pm} \to \tilde{\tau}_1^{\pm}\nu_\tau$ (68%) $\Rightarrow$ many τ's. Not atypical.

Have simulated 100k events with GEANT/Atlsim ($\sim$ 30m/event) and reconstructed them with Athena 6.0.3 ($\sim$ 1m/event).

Main emphasis is on testing Athena reconstruction.

Some physics results using Point 5 cuts. Fast simulation $\Rightarrow$ small SM background after these cuts.

Results presented at Athens Physics Workshop [Athens].

Jet Reconstruction and Calibration

Have used two Athena jet algorithms for SUSY studies:

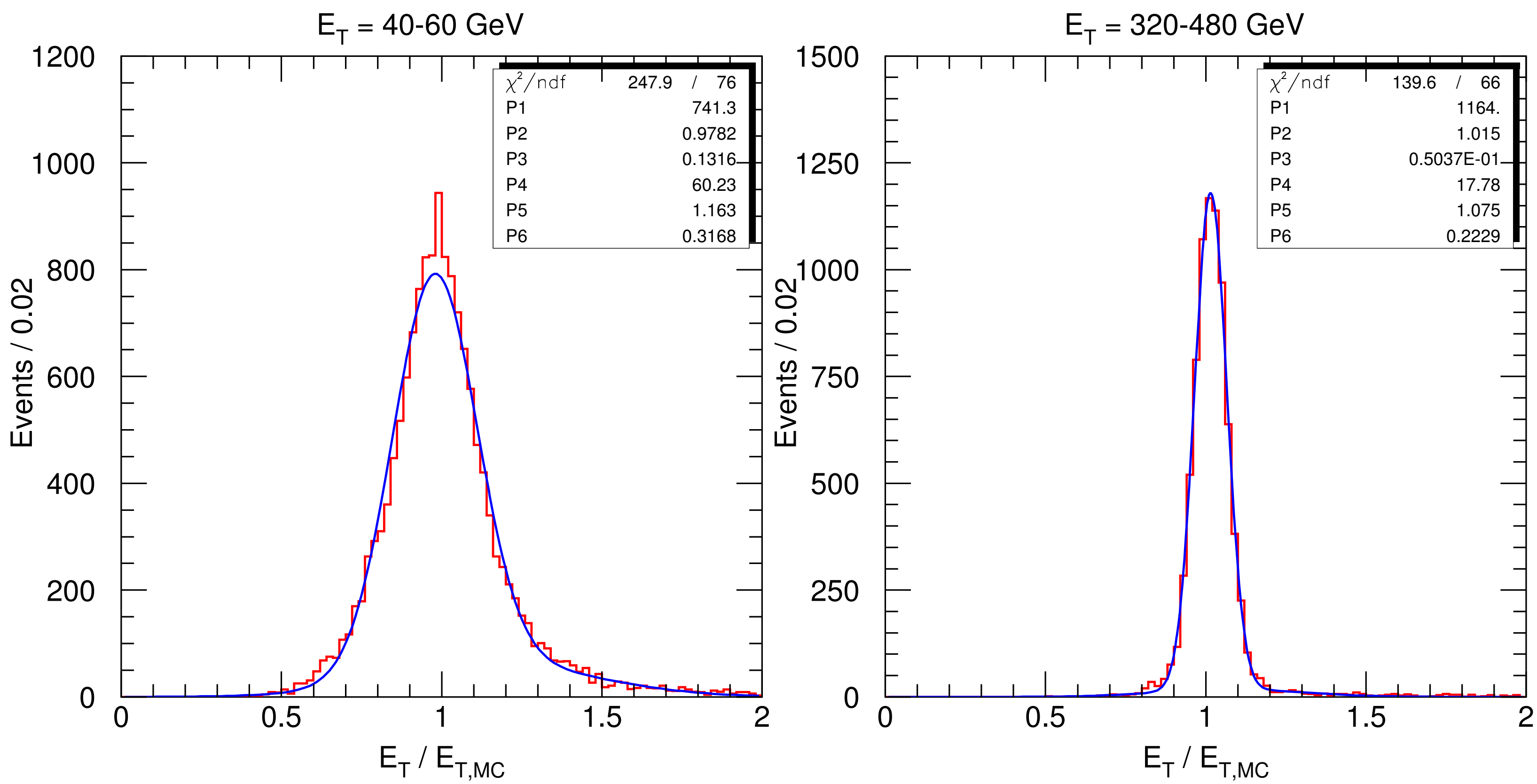
- (Seeded) Cone: Iterate cone with fixed R. Not infrared safe, but works OK in practice.
- K_T: Well optimized Cambridge code, but still $T \propto N^3$.

Calorimeter in Athena is calibrated at EM scale, so $\sim 15\%$ low for jets. *TDR* corrected for this using sampling weights.

H1 algorithm: EM showers are denser than hadronic ones, so use unit weight for high E_T-cells, larger weight for low-E_T ones.

To determine weights, sum cells in E_T bins for each jet and calorimeter section. Fit weights by comparing calorimeter jet with nearest jet made from MC particles using same jet algorithm.

Resulting resolution for 2 DC1 QCD jet samples:



Mean response is about correct and Resolution also somewhat better.

Same H1-style weights also improve $\not\!\!E_T$ resolution.

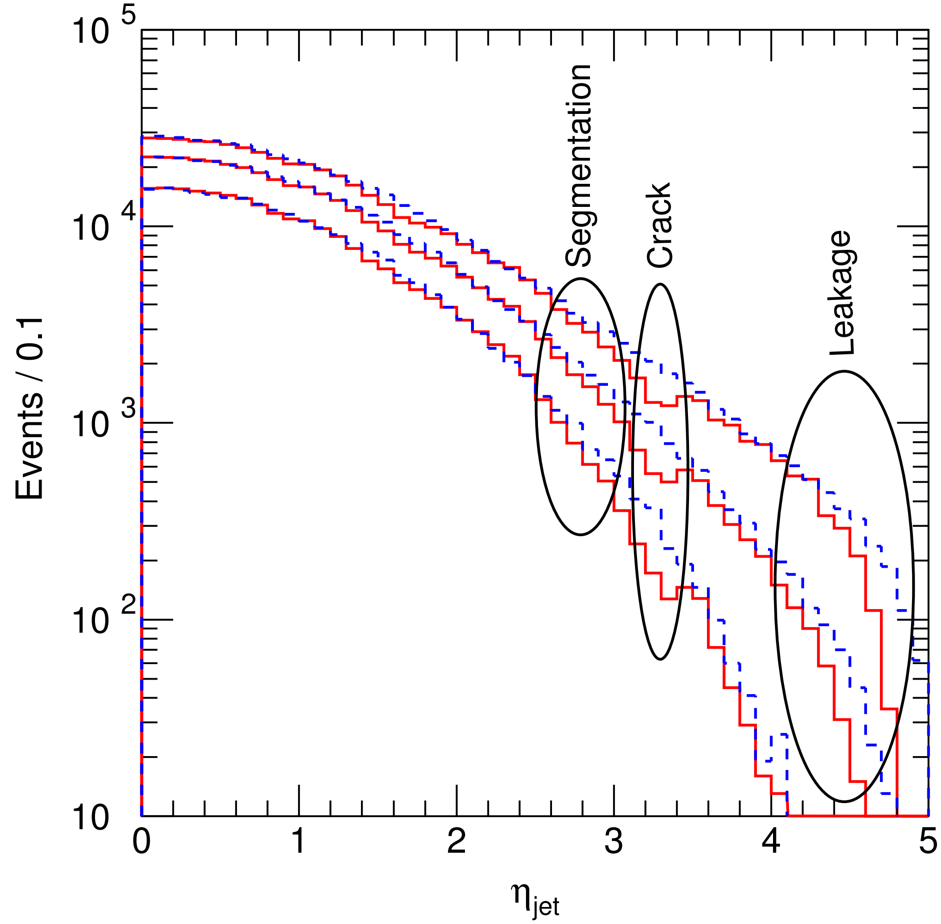
Reconstruct jets in SUSY using same weights, and again compare with closest MC jet. Compare reconstructed (solid) and Monte Carlo (dash) jets for $E_T > 25, 50, 100\,\mathrm{GeV}$:

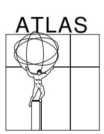
H1 calibration also works for SUSY sample dominated by quark jets, but observe some problems:

Calorimeter segmentation changes at $\eta = 2.5$.

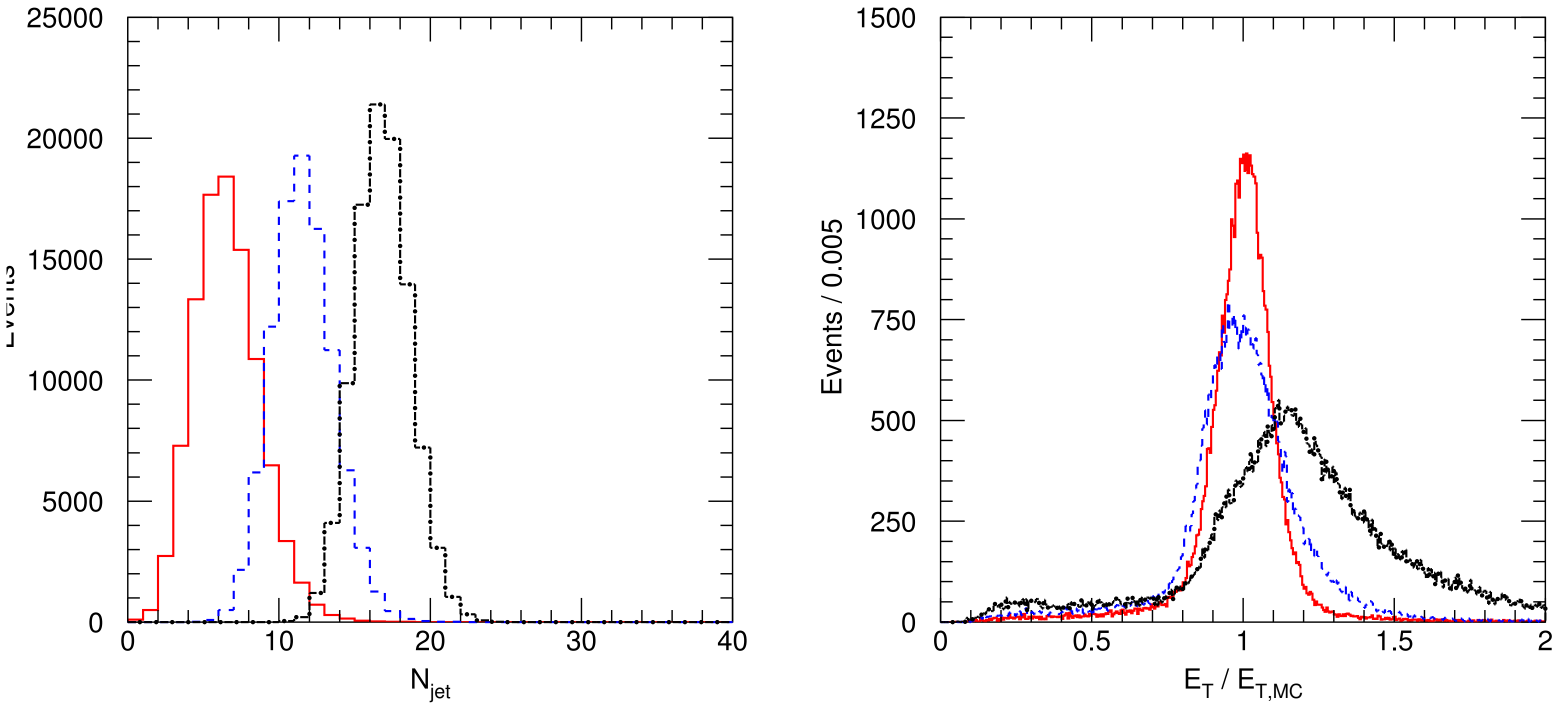
Crack between endcap and forward calorimeters at $\eta = 3.2$.

Shower leakage at large η.



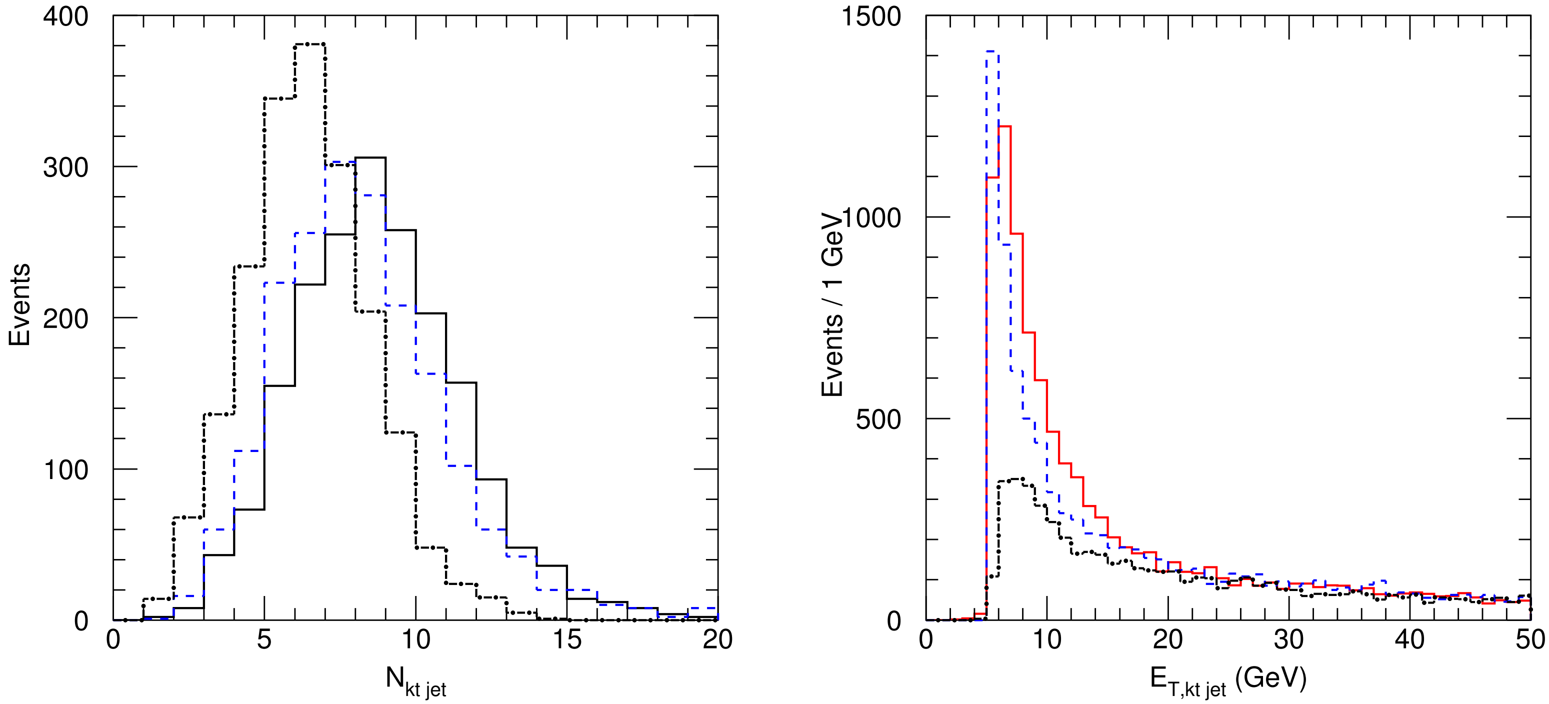


Just before Athens, included electronic noise but not pileup. KT algoritm requires $E > 0$. Huge effect with $E = 0$ cut (dash-dot), still large with $E = 2\sigma_E$ cut (dash) on multiplicity and resolution for $E_T = 80$–$120\,\mathrm{GeV}$:



Smaller effect for cone algorithm with $R = 0.4$, so many fewer towers.

Since Athens, have implemented cancellation of $E < 0$ `CaloTower`'s with nearby $E > 0$ ones and applied H1 weights before clustering. Much better agreement between Monte Carlo (dash) jets and reconstructed ones with (solid) than without (dashdot) preweighting:

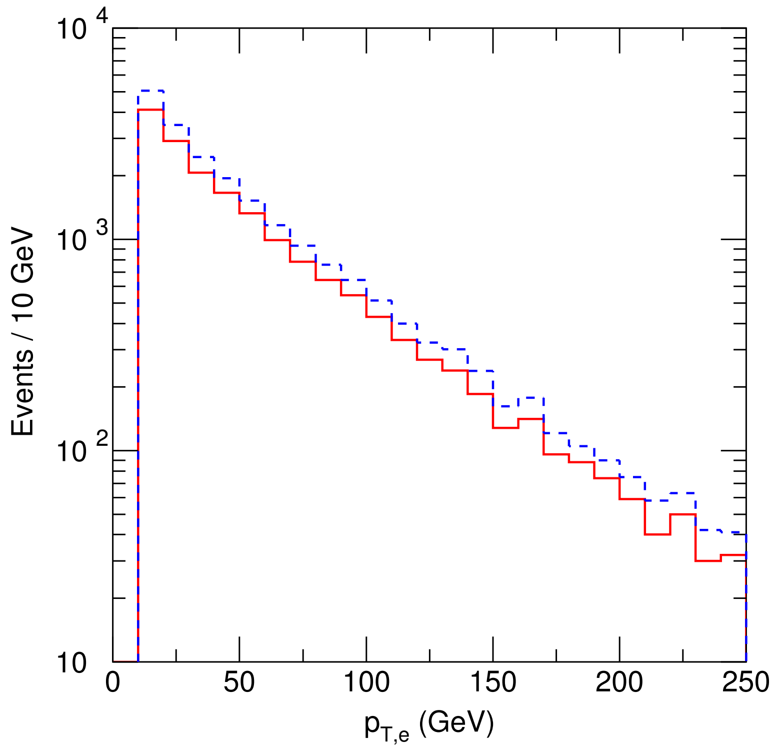


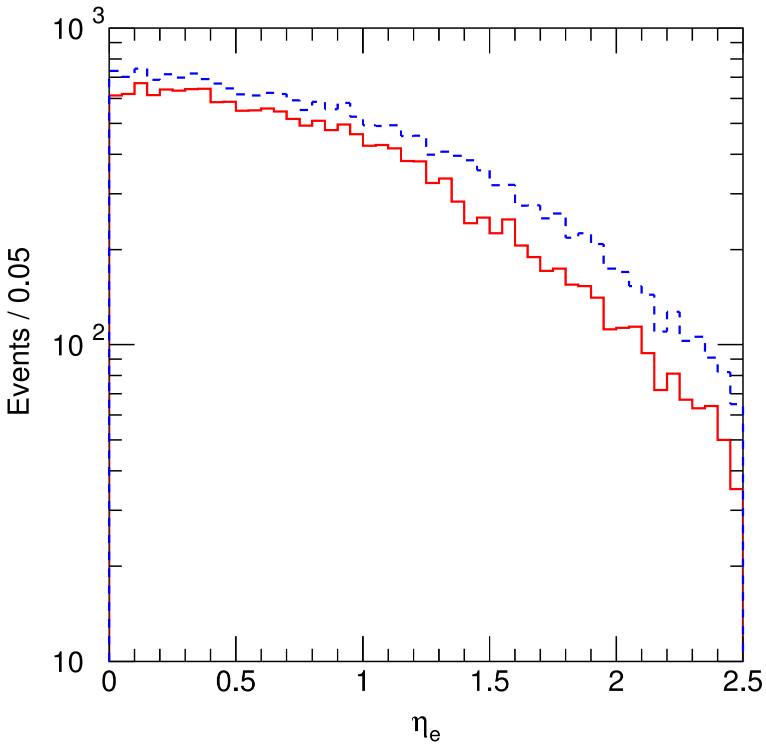
Still not perfect; need a lot of work to achieve 1% hadronic energy scale and best possible jet energy resolution.

Electron Reconstruction

Electrons identified by shower shape and track match.

Require `eg_IsEM` $= 0$ (EM shape) and $0.7 <$ `eg_eoverp` < 1.3 (track match) gives mediocre acceptance in endcap:

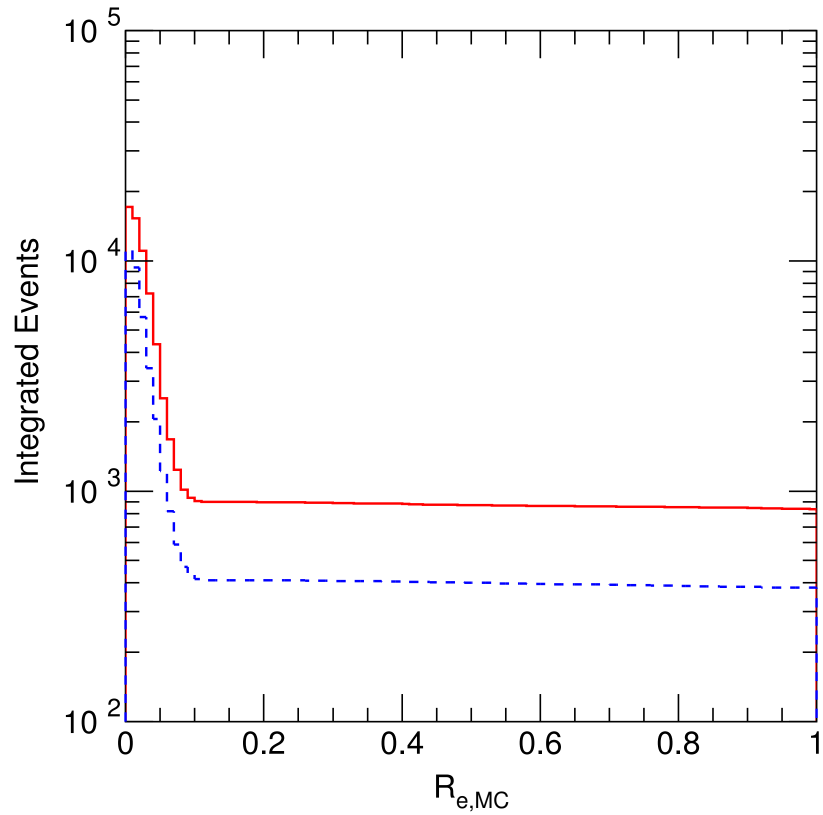




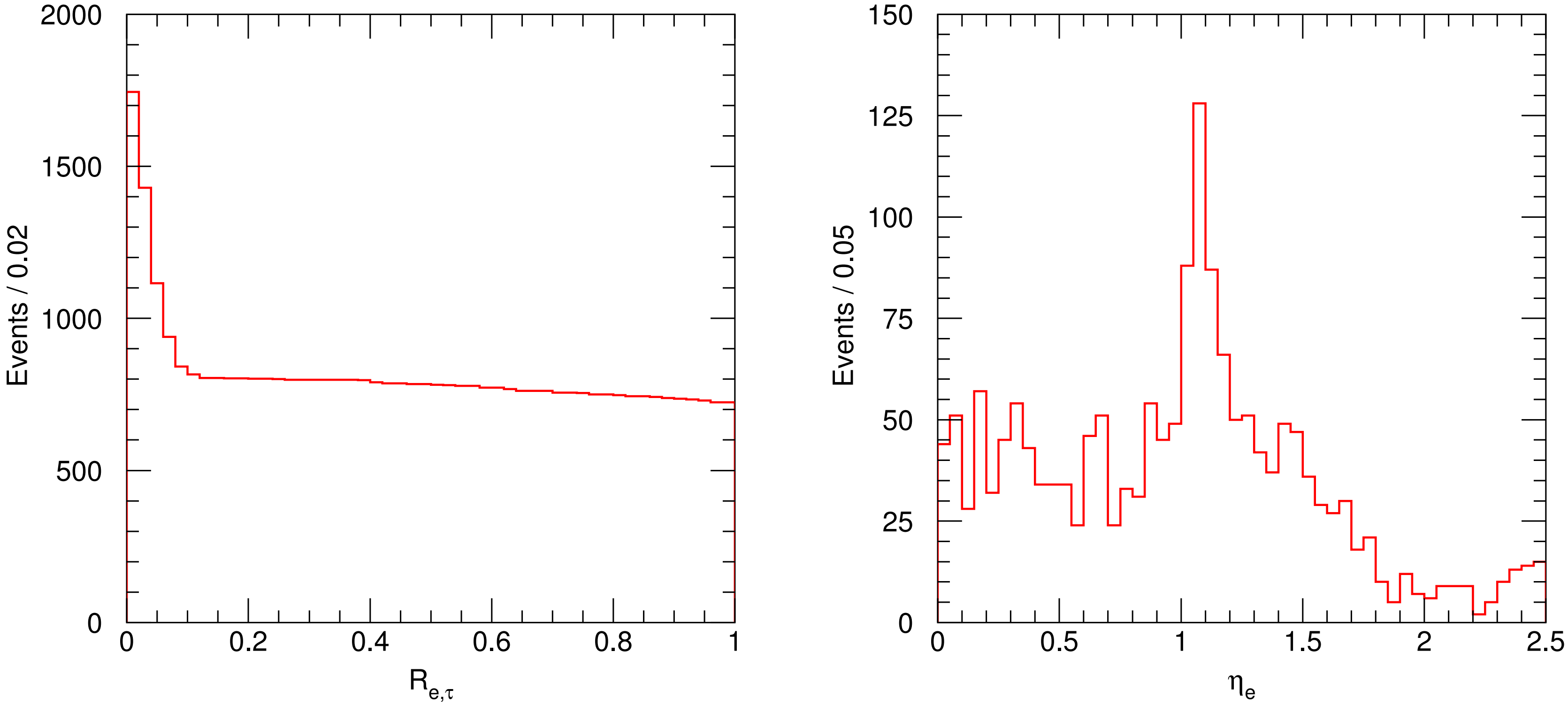
Plot integral distribution for $E_T > 10, 25\,\mathrm{GeV}$ of distance R between reconstructed e and closest MC one.

Mostly $R < 0.1$, but see $\sim 4\%$ fakes for $E_T > 25\,\mathrm{GeV}$.

If fakes are from jets, 6.3 jets and 0.16 electrons per event imply fake e/j rate is $\sim 10^{-3}$, worse than expected.

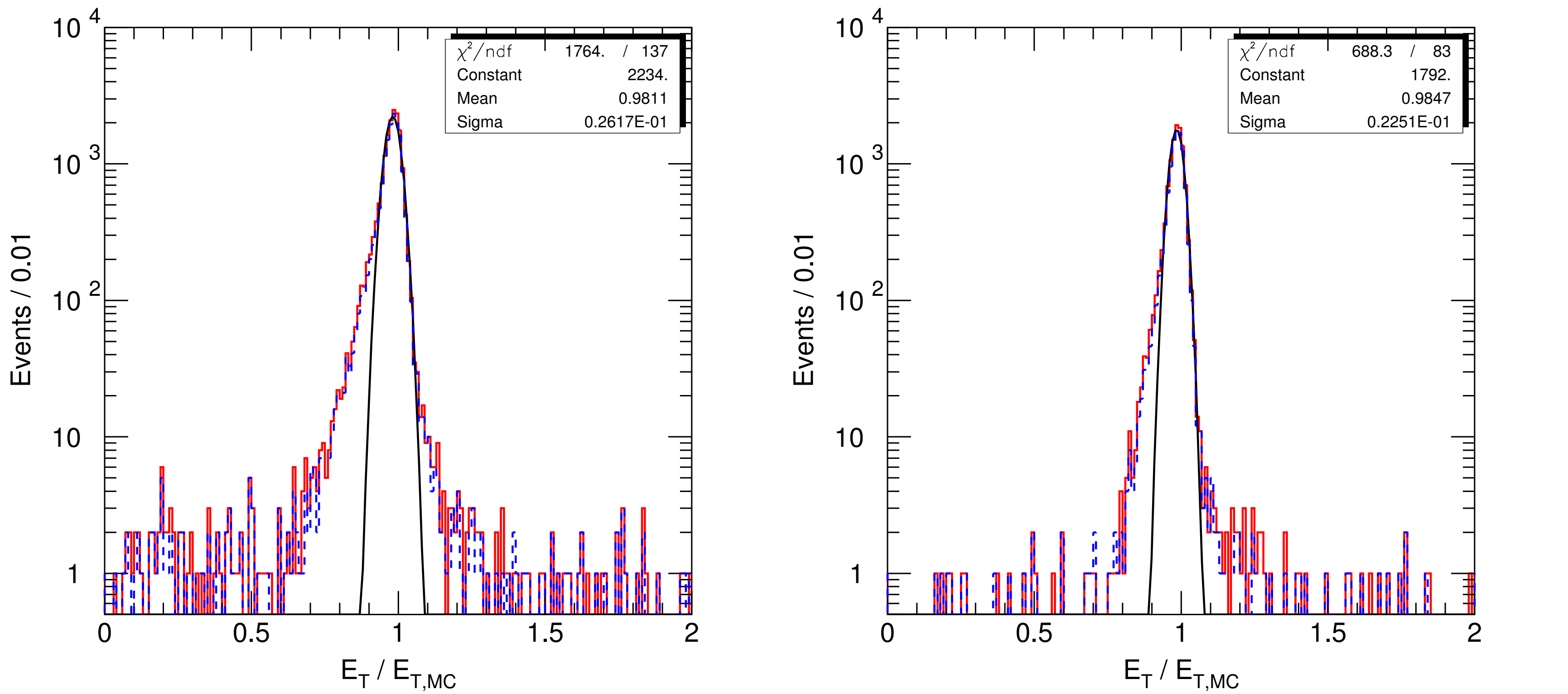


But half of fake e's are close to τ's, more like e's than jets. Fake e's peak at $\eta = 1.1$ near gap in HCAL:



Obviously need more work on *e* identification in complex events, e.g., with large τ background.

Resolution (compared to nearest MC e) for $E_T > 10, 25\,\mathrm{GeV}$:

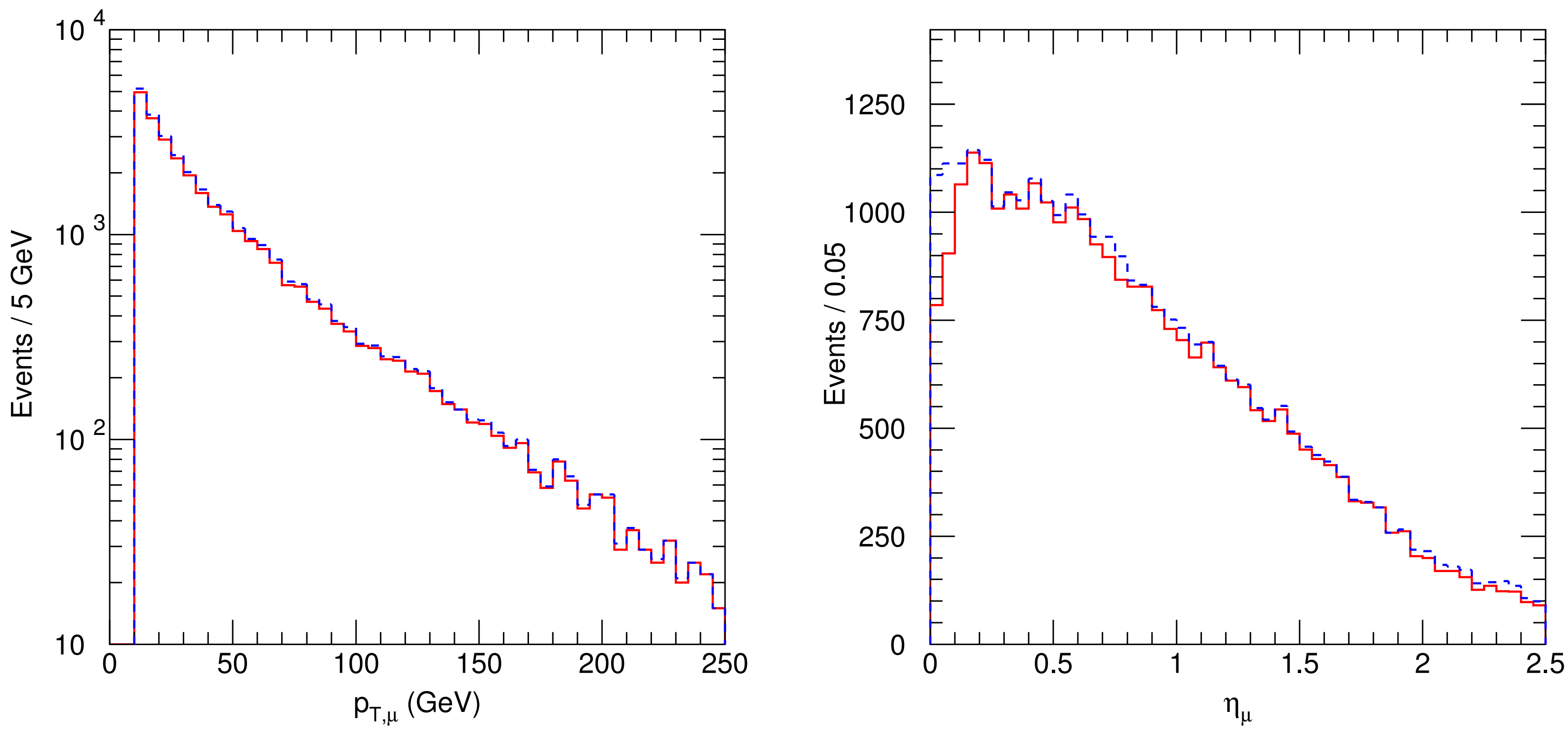


Mean correct to $\lesssim 2\%$. Need brem recovery for radiative tail. Other non-Gaussian tails need work.

Muons

MuonBox gives excellent results – better than 90% overall acceptance.

Dip in acceptance at $\eta = 0$ due to holes for services:

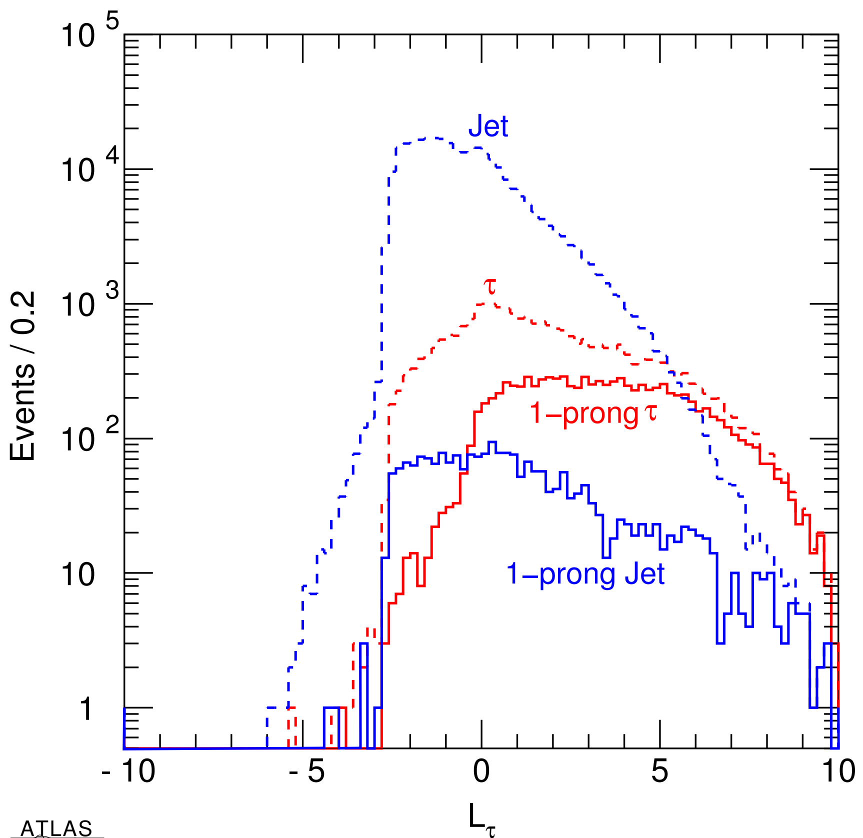


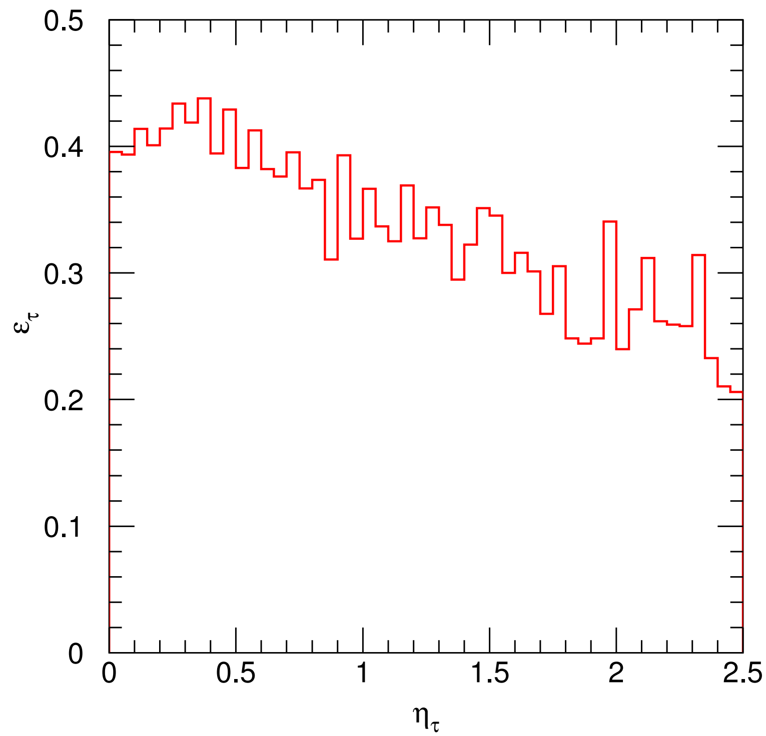
Moore and MuID still need work.

τ Reconstruction

τ's are important SUSY signature. Hadronic $\tau \Rightarrow$ 1 track with $p_T > 2\,\mathrm{GeV}$, $E_{T,\mathrm{had}} \neq 0$, and narrow shower in EM calorimeter.

Shower shape L_τ distributions for τ's and jets before (dashed) and after (solid) track cuts and resulting efficiency for $E_{T,\mathrm{vis}} > 35\,\mathrm{GeV}$:





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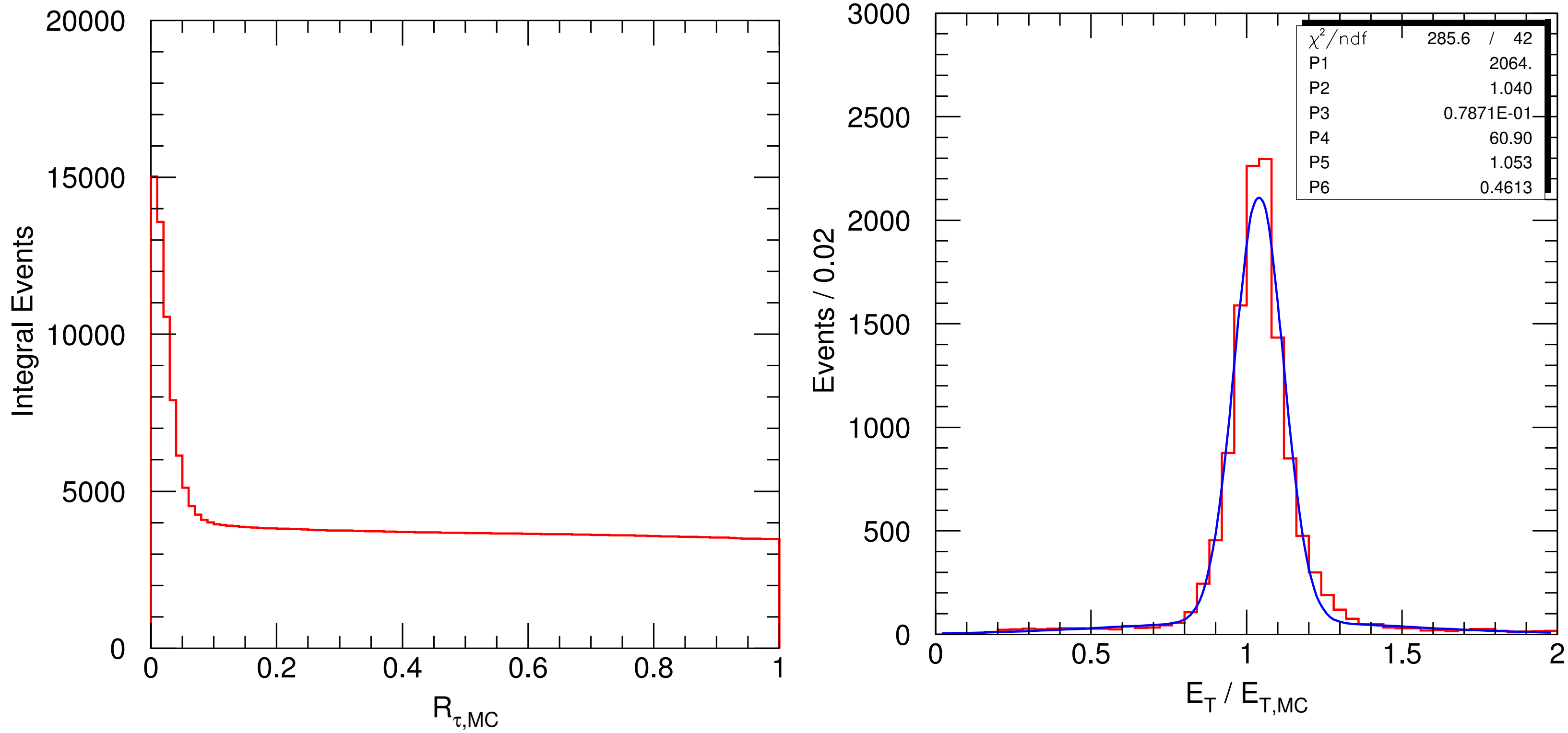
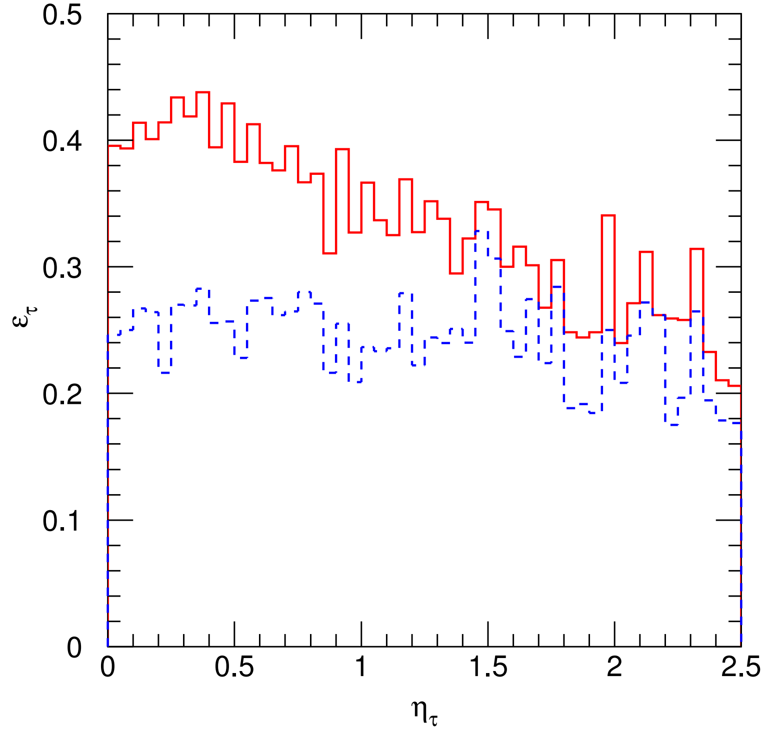
Matching in R of reconstructed to MC τ's and E_T resolution:

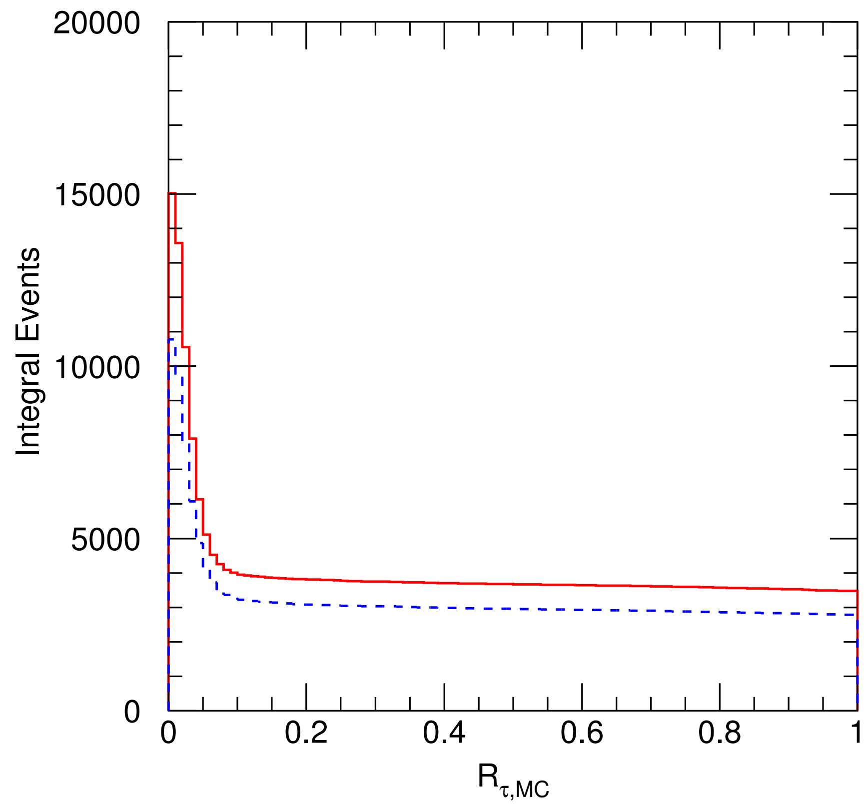


Significant background from mis-identified jets; $S/B \approx 2.8$.

Energy calibration for τ's with MC match is roughly OK.

Just before Athens, included calorimeter noise with 2σ cut but no pileup. Efficiency is worse, especially at low η, and S/B also degraded:





Need to retune τ selection cuts including noise and pileup.

ATLAS

SUSY Physics with Full Simulation

Use Point 5 selection cuts from *TDR*:

- ≥ 4 jets with $E_T > 100, 50, 50, 50\,\mathrm{GeV}$;
- $M_{\mathrm{eff}} > 800\,\mathrm{GeV}$;
- $\not{E}_T > \max(100\,\mathrm{GeV}, 0.2 M_{\mathrm{eff}})$.

Then expect negligible SM background, so just show SUSY distributions.

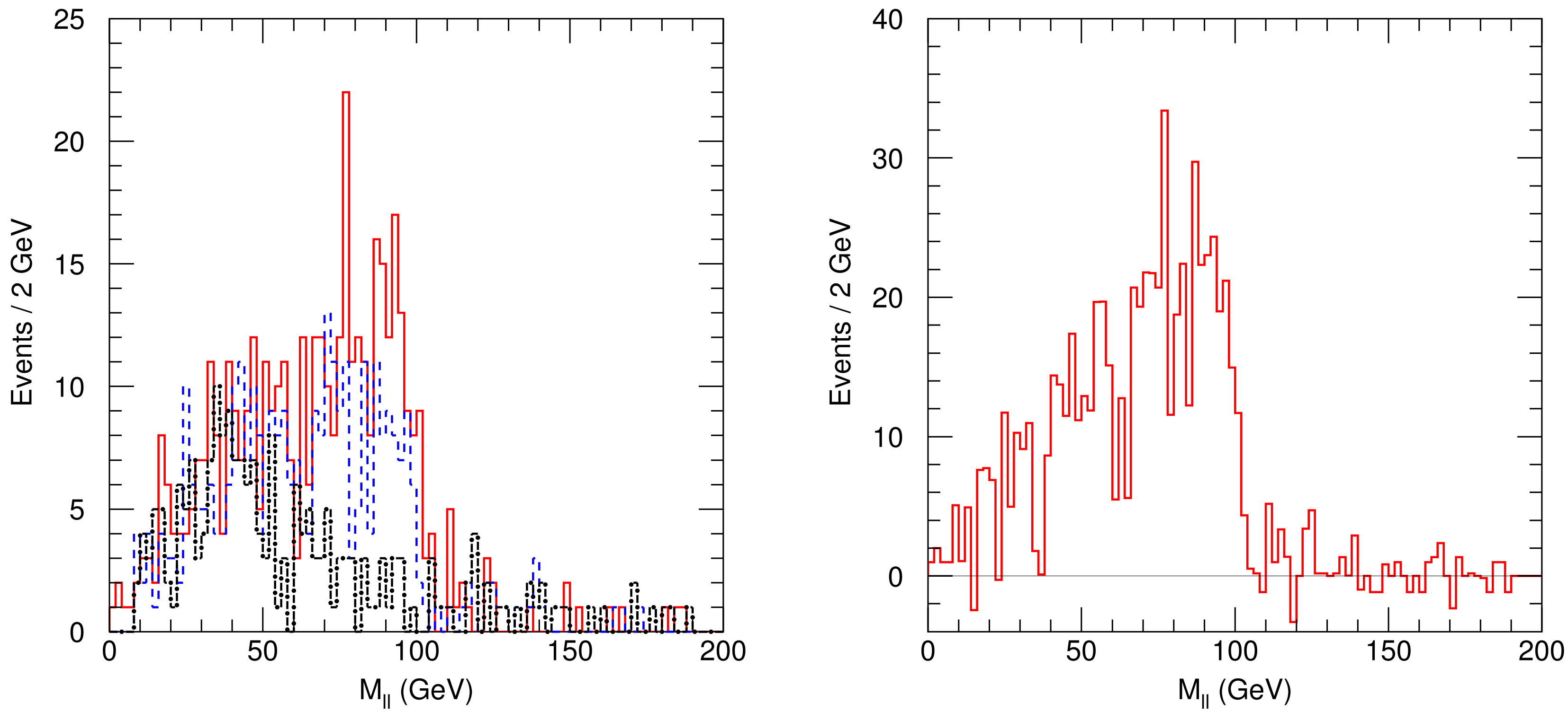
Recall $\tilde{\chi}_2^0 \to \tilde{\ell}_R^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^+ \ell^-$ has endpoint at

$$M_{\ell\ell}^{\max} = \sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)/M_{\tilde{\ell}}^2} = 100.16\,\mathrm{GeV}.$$

$e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ cancels backgrounds from independent decays.

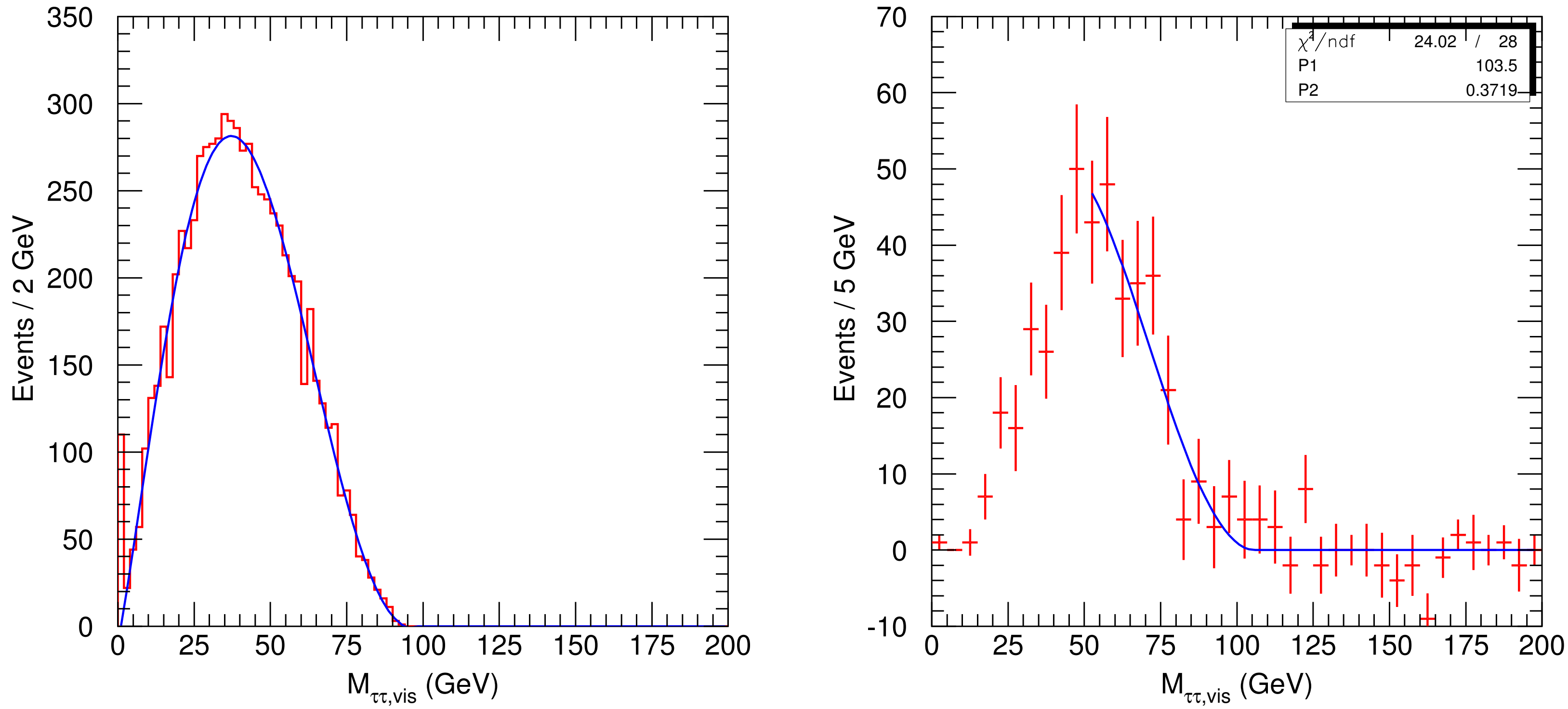
Correct E_e scale by 1.017 and weight each electron by 1.16 for relative acceptance. Then find correct endpoint after subtraction.

$\mu^+\mu^-$, e^+e^-, $e^\pm\mu^\mp$, and weighted $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$ masses:



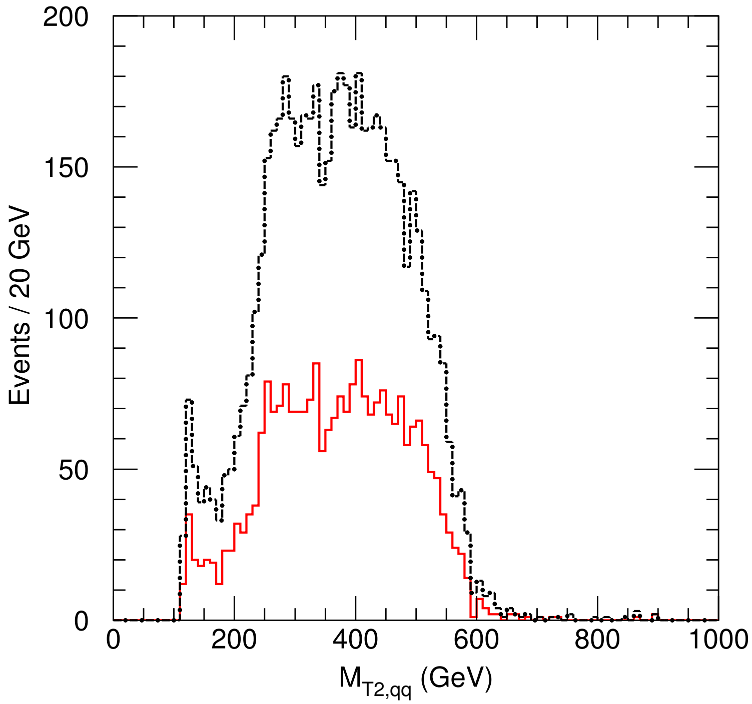
Main source of $\tilde{\chi}_2^0$ is $\tilde{q}_L \to \tilde{\chi}_2^0 q$. Assume 2 hardest jets are from $\tilde{q}_L$ and combine with dileptons. Find approximately right endpoints, but tails not yet understood.

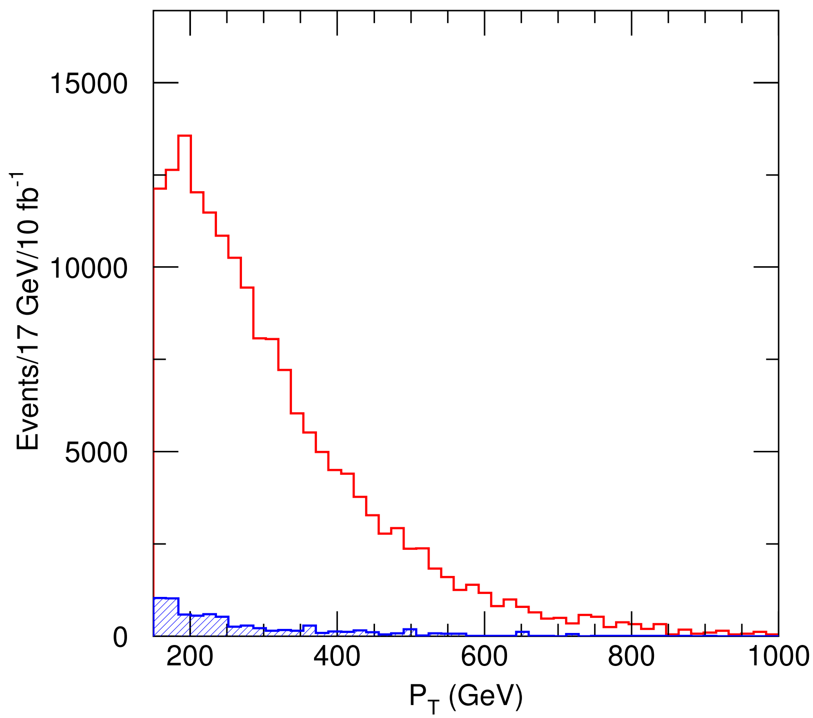
For $\tau^+\tau^-$ use all Monte Carlo $\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp$ events to find expected $M_{\tau\tau,\mathrm{vis}}$ distribution. Fit shape to reconstructed $\tau^+\tau^- - \tau^\pm\tau^\pm$ mass:



Fit gives 103.5 ± 4.9 GeV, consistent with 98.3 GeV. Sensitive to fit range since $M_{\tau\tau,\mathrm{vis}}$ distorted by cuts at low mass. Shape also depends on τ polarizations, but effect not easy to observe [Vacavant].

$\tilde{q}_R\tilde{q}_R \to \tilde{\chi}_1^0 q \tilde{\chi}_1^0 q$ gives 2 jets + $\not{E}_T$. Veto jets with $E_T > 25(50)$ GeV and plot M_{T2} using known $M_{\tilde{\chi}_1^0}$. True endpoint is 611 GeV. Compare with single jet distribution for Point 6 [Athens, TDR]:





Much better result from full simulation using M_{T2} than from fast simulation using p_T(!).

Outlook

If TeV scale SUSY exists, ATLAS should find it at LHC. Have developed tools for making precision SUSY measurements. Understand broad outline of initial program.

Much more work on SUSY analysis at fast simulation level is needed. Some examples:

- Study $M_{\tilde{\chi}_1^0}$ measurement for whole SUGRA range allowed by CDM.
- Develop techniques for difficult modes, e.g., τ decays, $\tilde{g} \to t\bar{b}\tilde{\chi}_i^-$.
- Learn to measure cross sections and branching ratios.

Full simulation study for Athens was quite productive. But we are still developing Athena, not yet probing performance of ATLAS detector.

Will simulate more SUSY points and continue Athena development.

A lot more remains to be done. Please join the ATLAS SUSY group.

References

[TDR] ATLAS Collaboration, *Detector and Physics Performance Technical Design Report*, CERN/LHCC 99-14.

[Intro] For selected introductory references on SUSY see `http://paige.home.cern.ch/paige/susy/susyrefs.html`.

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[Vacavant] Talk by L. Vacavant, Lund Physics Workshop, `http://agenda.cern.ch/fullAgenda.php?ida=a0159`.